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Foreword

SYNER-G is a European collaborative research project funded by European Commission (Seventh Framework Program, Theme 6: Environment) under Grant Agreement no. 244061. The primary purpose of SYNER-G is to develop an integrated methodology for the systemic seismic vulnerability and risk analysis of buildings, transportation and utility networks and critical facilities, considering for the interactions between different components and systems. The whole methodology is implemented in an open source software tool and is validated in selected case studies. The research consortium relies on the active participation of twelve entities from Europe, one from USA and one from Japan. The consortium includes partners from the consulting and the insurance industry.

SYNER-G developed an innovative methodological framework for the assessment of physical as well as socio-economic seismic vulnerability and risk at the urban/regional level. The built environment is modelled according to a detailed taxonomy, grouped into the following categories: buildings, transportation and utility networks, and critical facilities. Each category may have several types of components and systems. The framework encompasses in an integrated fashion all aspects in the chain, from hazard to the vulnerability assessment of components and systems and to the socio-economic impacts of an earthquake, accounting for all relevant uncertainties within an efficient quantitative simulation scheme, and modelling interactions between the multiple component systems.

The methodology and software tools are validated in selected sites and systems in urban and regional scale: city of Thessaloniki (Greece), city of Vienna (Austria), harbour of Thessaloniki, gas system of L'Aquila in Italy, electric power network, roadway network and hospital facility again in Italy.

The scope of the present series of Reference Reports is to document the methods, procedures, tools and applications that have been developed in SYNER-G. The reports are intended to researchers, professionals, stakeholders as well as representatives from civil protection, insurance and industry areas involved in seismic risk assessment and management.

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Abstract

A unified approach for modelling **shelter needs** and **health impacts** caused by earthquake damage which integrates social vulnerability into the physical systems modelling approaches has been developed. The shelter needs and health impact models discussed here brings together the state-of-the-art social loss estimation models into a comprehensive modelling approach based on *multi-criteria decision support*, which provides decision makers with a dynamic platform to capture post-disaster emergency shelter demand and health impact decisions. The focus in the shelter needs model is to obtain shelter demand as a consequence of building usability, building habitability and social vulnerability of the affected population rather than building damage alone. The shelter model simulates households' decision-making and considers physical, socio-economic, climatic, spatial and temporal factors in addition to modelled building damage states (input from WP3 and WP5). The health impact model combines a new semi-empirical methodology for casualty estimation with models of health impact vulnerability, transportation accessibility and healthcare capacity to obtain a holistic assessment of health impacts in the emergency period after earthquakes. A group of proposed socio-economic indicators were derived based on an in-depth study of disaster literature for each of the shelter, health and transport accessibility models, and harmonized based on data available for Europe from the EUROSTAT Urban Audit Database.

Keywords: indicators, shelter, health, social vulnerability, social impacts, mcda

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1 Introduction and objectives

1.1 INTRODUCTION

Recent decades have seen an exponential growth in the physical impacts and losses from earthquakes throughout the world. The Great Wenchuan Earthquake in May 2008, the Haitian Earthquake of 2010, and the 2011 Great East Japan Earthquake provide poignant reminders of the susceptibility of communities to devastating loss of lives, livelihoods, and property from earthquake events. These disasters, plus many other smaller ones, illustrate how earthquakes adversely impact people and the communities in which they live, and the impacts of such events occur across geographic boundaries and at multiple scales affecting governments, institutions, economic sectors, livelihoods, and people. A long history of human development in seismic regions has resulted in increased susceptibility of populations to seismic hazards and their effects.

There is a consensus within the scientific community that disasters associated with earthquakes are not wholly the product of the physical impacts of natural hazard events. Rather, these disasters are the outcome of the interaction between the earth's biophysical systems, the engineered environment, and the social conditions inherent at particular places. It is increasingly becoming clear that some people and groups are impacted differentially by damaging events, react differently in an event's aftermath, adjust to its circumstances in dissimilar ways, and recover in a differential manner. These circumstances have stimulated great interest in understanding how to manage the associated seismic risk, adverse impacts, and loss.

The current state of the art in earthquake loss estimation (ELE) software provides several parameters of direct socio-economic consequences which are needed to support effective decision making (Social and Economic losses for existing ELE software packages are reviewed in Appendix A). These include parameters such as casualties, displaced persons, and business failures by industry, for example. However, poor linkages between damage to physical systems and resultant social consequences remain a significant limitation with existing hazard loss estimation models (Bostrom et al, 2008). A new direction with earthquake loss estimation software, which has been developed by researchers of the Mid America Earthquake Centre, is the inclusion of social vulnerability into the modelling approaches (Elnashai, 2009). This allows for a greater level of information to be obtained by linking social vulnerability models (often limited to conceptual frameworks) to loss estimation models for use in disaster response (e.g. homeless shelter needs and required supply). Other socio-economic impacts disturbing the fabric of society such as the loss of rental vs. owner-occupied housing (drivers into post-event housing recovery strategies), disruption to residents based on various forms of housing, loss of public services, coping of special needs populations in emergency shelter, and disruptions to institutions and governance are also being studied by various researchers in the field (Chang et al., 2009; Wright and Johnston 2010; Khazai et al., 2011a). However, to date, no systemic approach exists that quantitatively brings together these disparate research areas into a comprehensive modelling tool, which provides decision makers with a dynamic platform to capture post-disaster decisions, interactions and changes over time.

At the core of the SYNER-G Project are the development of state-of-the-art modelling capabilities and a suite of software tools that can be utilized for the assessment and communication of earthquake risk which integrates social vulnerability with physical risk modelling parameters. For a more holistic assessment of adverse earthquake impacts affecting society, a set of methods, indicators and tools have been incorporated into the SYNER-G modelling framework to assess seismic risk and impact potential beyond the estimation of direct physical impacts and loss of life. With increased exposure of people, livelihoods, and property to earthquake risk, the potential for social and economic impacts of earthquakes cannot be ignored. Not only is it vital to evaluate and benchmark the conditions within social systems that lead to adverse earthquake impacts and loss, but it is equally important to measure the capacity of populations to respond to damaging events as well as to provide a set of metrics for priority setting and decision-making. Indicators and composite indices are increasingly being utilized to accomplish these tasks.

1.2 OBJECTIVES

One of the aims in SYNER-G is to develop a unified approach for modelling socio-economic impacts caused by earthquake damage which integrates social vulnerability into the physical systems modelling approaches (Work Package 4). In many earthquake loss estimation models socio-economic losses are computed as linear damage-consequence functions without consideration of social vulnerability. Contributing to the challenge of integrating social vulnerability with physical damage/performance models is the fact that social vulnerability is a fundamentally relative phenomenon and not something that can be directly observed and measured.

In SYNER-G social losses (e.g., number of displaced people and casualties) are computed as an integrated function of hazard intensity, systemic vulnerability of physical systems and the social vulnerability of the population at risk. The integrated approach proposed in SYNER-G provides a framework to link the degree of damage and performance of inter-related physical systems to vulnerabilities and coping capacities in society to assess: (1) Impacts on displaced populations and their shelter needs, and (2) Health impacts on exposed populations and their health-care needs. This way of conceptualizing the integrated framework emphasizes the importance of understanding the interrelations between physical and social systems. In other words, how direct physical losses can potentially aggravate existing vulnerabilities in society and how vulnerabilities in society can ultimately lead to greater impacts from physical damage and losses.

Thus, one of the main objectives has been adoption of an indicator system and common nomenclature which posits social vulnerability in relation to the vulnerability of the physical system. For example, the number of displaced persons was not computed as a function of damaged buildings alone, but derived as a function of the habitability of buildings (defined by the tolerance to utility loss for different levels of building damage and weather conditions); and a set of key socio-economic indicators influencing a population to leave their homes and seek or not seek public shelter.

Emphasis in SYNER-G is placed on the early emergency relief and recovery period where the rapid provisioning of food, water, shelter and emergency healthcare services are the most important interventions to keep people alive and safe. Thus, the focus will be on integrating models of social impact with loss estimation models for use in disaster response and recovery planning. This includes models for estimating post-disaster shelter needs and health impacts. Furthermore, non-availability of lifeline networks (roads, pipelines, electricity and water supply) have important consequences on the recovery process and contribute to increased social disruptions within shelter and health sectors. In WP4 the impact of disruptions of the transportation system and utility systems on shelter and health systems is investigated (Fig. 1.1).

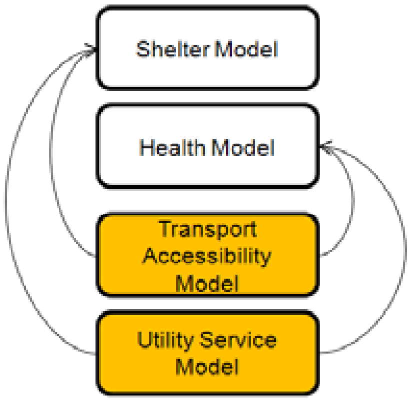

Fig. 1.1 Overview of the sectors analysed in WP4

The overall objective of WP4 is to transfer the interdependencies and consequences of losses in physical systems (buildings, utility and transportation network components, critical facilities) to their consequences on society as measurable indicators and values of socio-economic losses upon which policy and decision-making can take place. Metrics that describe direct social consequences; such as number of casualties, number of displaced people, emergency shelter needs, demand on healthcare systems and other critical facilities are key inputs for emergency response planning and preparedness. Poor linkages between damage to physical systems and resultant social consequences remain a significant limitation with existing hazard loss estimation models.

The shelter needs and health impact models discussed here will bring together the state-of-the-art social loss estimation models into a comprehensive modelling approach based on multi-criteria decision support, which provides decision makers with a dynamic platform to capture post-disaster emergency shelter demand and health impact decisions. The focus in the shelter needs model is to obtain shelter demand as a consequence of building usability, building habitability and social vulnerability of the affected population rather than building damage alone. The shelter model simulates households' decision-making and considers physical, socio-economic, climatic, spatial and temporal factors in addition to modelled building damage states. The vulnerability and coping capacities of ‘at risk’ populations affects health impacts of earthquakes. The aim here is to link social vulnerability and coping capacity of the affected population with other components of the health impact model - casualty estimates, healthcare functionality, and transportation accessibility - within a multi-tiered health impact model. The proposed health impact model will describe the processes and links between socio-demographic, environmental, epidemiological and health behaviour parameters to increased short-term health impacts. Furthermore, healthcare systems parameters will be integrated in a healthcare capacity model to assess secondary impacts on the overall health care delivery to the affected population.

1.3 SPATIAL CHARACTERISATION AND APPROACH

The impact of an earthquake on society evolves in space with the time elapsed from the event. Different stakeholders have different interests and play distinct roles in the various phases of the disaster. Correspondingly they look at impact assessments according to their own particular needs and mandates. These three dimensions (time, space, stakeholders) are represented in Fig. 1.2 which allows the vulnerability and impacts on society and its built systems to be operationalized. In particular, along the time-dimension three periods of a disaster – emergency, recovery and reconstruction - can be identified. The first period constitutes the immediate aftermath of the event and its short-term consequences where the damaged Infrastructure operates in a state of emergency. In this phase emergency managers must deal with the demand generated by damaged infrastructure in terms of temporary shelter needs or hospitalization and treatment of victims. In the mid-term recovery period, while the infrastructure progressively returns to a new state of normal functionality, the disruptions to businesses might be of interest to stakeholders in the insurance sector. In the long-term reconstruction period, national governments and multi-lateral organizations have to grapple with the costs of permanently rebuilding or upgrading/retrofitting damaged infrastructure, and mitigate the risk from the next event.

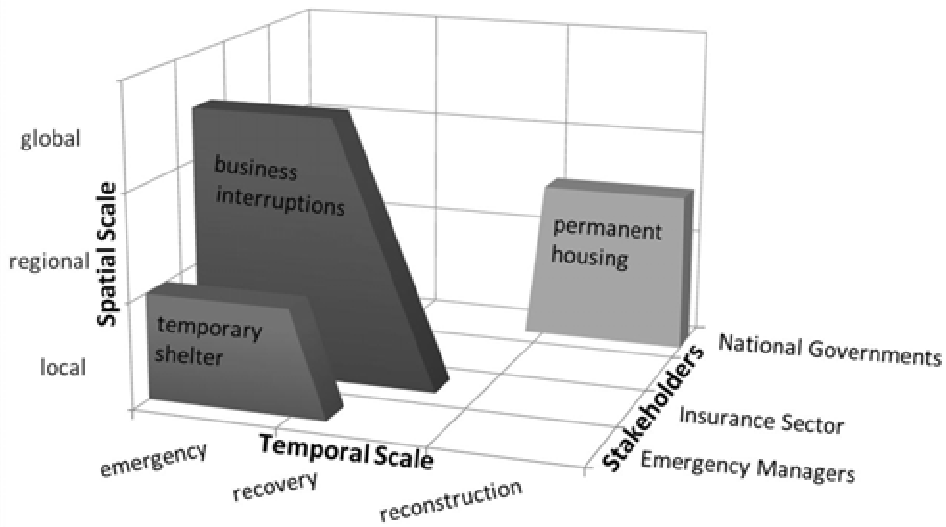

Fig. 1.2 The three dimensions in an Infrastructure vulnerability and impact study

From the perspective of systemic studies there are two distinct phases which are commonly addressed:

- Emergency phase: short-term (a few days/weeks) at the urban/regional scale (e.g. Franchin *et al* 2006, Nuti and Vanzi 1998)
- Economic recovery phase: medium to long-term, at the regional/national scale (Karaca 2005)

Furthermore, the position on the "time axis" of the analyst/observer with respect to the time-frame changes the goal of the systemic study:

- Outside/before the time-frame: the goal of the system analyst is to forecast the impact in order to set-up preparedness, planning and mitigation measures. It is important to underline how the information basis in this case can be considered as constant.
- Within the time-frame: the goal of the system analyst is that of providing the managers with a real-time decision support system, which updates the Infrastructure state based on the continuously incoming flow of information.
- After the time-frame: the goal of the system analyst is to validate the models against occurred events.

The developed methodology focuses on the *short-term* only, with *Emergency Managers* as the reference stakeholders, and with the goal of *forecasting* before the event occurs, the expected impact in terms of dead, injured and displaced population, for the purpose of planning and implementing risk mitigation measures.

2 State-of-the-art review

A wide variety of models, methods and tools exist to assess the impacts and risks of disasters beyond the direct destruction of structures. Research on the societal dimensions of earthquakes has become a deeply interdisciplinary science and much of the research has been focused on the design of models which explain social vulnerability and the root causes which create it (Tierney, 2010; Wisner et al., 2004; Blaikie et al., 1994). However, work remains on “operationalization”, which is critical for translating conceptual frameworks into practical tools that can be used for measuring and communicating societal impacts of disasters. Indicator-based approaches are used increasingly to measure social and economic impacts across regions, countries, and populations (Jaeger 2002; Gallopin 1997; Cutter et al, 2003). Indicator-based approaches constitute a transparent possibility in providing an operational representation (of not directly measurable conditions) regarding the susceptibility, coping capacity and resilience of a system to disaster impacts (. In addition, some indicator frameworks depict/measure how vulnerability is influenced by resilience; i.e. the adaptive ability of a socio-economic system to absorb negative impacts as result of its capacity to anticipate, cope and recover quickly from damaging events (Bogardi and Brauch, 2005, Rose 2005).

Bearing in mind that the goal of this project is to produce operational tools that offer quantitative assessment of social impacts of disasters, the following presents a summary of the state-of-the-art in terms of tools, models and toolboxes for assessing the socio-economic impacts and risks of natural disasters with a focus on earthquake risk. A full list of software and indices used in socio-economic impact assessment is also reviewed and presented in Appendix A.

2.1 SOCIAL IMPACT ASSESSMENT

While there are many areas and topics that fall under the umbrella of societal impacts and losses, the approaches that are briefly reviewed here include: Social Vulnerability Models; Shelter and Housing Models; Health and Healthcare Systems Models; and Urban Recovery Models.

Today’s state-of-the-art risk models produce reasonably accurate estimates of physical damage to buildings and infrastructure systems, however, **poor linkages between damage to physical systems and differential socio-economic vulnerability** remain a significant limitation with existing hazard loss estimation models (Bostrom et al, 2008). Because of the great detail entailed in earthquake loss estimation models, there is potential to better integrate social vulnerability models in estimating important parameters of social impact, such as emergency shelter demand, and impact on health and health systems. A major contribution to the state-of-the-art has been development of integrated methods of physical and social vulnerability for evaluating impact on shelter and health systems (Chang et al., 2009; Wright and Johnston 2010; Khazai et al., 2011).Thus, the basis of the proposed approaches is to quantitatively derive social losses from disasters, by linking physical damage models with models of differential vulnerabilities and coping capacities at different scales in society.

Another important research direction has been the development of decision-support tools and **urban recovery models** for pre- and post-disaster use. Current loss estimation models are fundamentally static in concept, and thus a major challenge is to move towards more dynamic recovery models that can capture post-disaster decisions, interactions and changes over time. A remarkable advance in this area has been the development of quantitative resilience frameworks by *MCEER* researchers represented in this consortium. These include methods to quantitatively assess and enhance the seismic resilience of communities (Bruneau et al., 2003); simulation models of urban disaster recovery (Chang and Miles, 2003; Miles and Chang 2006, 2007); and methods for measuring economic resilience to disasters (Rose, 2005).

2.1.1 Social vulnerability and resilience models

Various theoretical vulnerability frameworks have been introduced for which the conceptual lineages can be traced to three main areas: (a) studies that draw heavily from risk/hazard approaches (Blaikie et al., 1994; Wisner et al., 2004); (b) the application of political-ecological and/or political-economic frameworks (Adger 2006; Cutter et al., 2003) and (c) recent research on vulnerability inspired by the concept of resilience in ecology (Cutter, 2010; Eakin and Luers, 2006). Although definitions and applications of social vulnerability vary within the literature (Cutter 1996), the concept is often described as the potential for harm and the ability of an individual or community to protect itself from damaging events (Wood et al. 2010). In contrast to vulnerability research which focuses on the factors making people less able to withstand, respond and recover from a hazard, some researchers have focused on resilience as the ability to cope with the situation during and after hazards. Tierney (2006) defined inherent resilience as “ability to withstand disasters without suffering extensive loss and disruption”, and distinguished from the adaptive resilience, which includes skills around the “ability to adapt and improvise, and access resources following disasters”. An interesting framework for vulnerability has been proposed by Pelling (2003) which encompasses vulnerability in terms of exposure, resistance and resilience. In this model, exposure is related to the location of the system or element with respect to the hazard and the environmental surroundings; resistance is related to the economical, psychological, and physical health of systems of maintenance, as well as the capacity of individuals or communities to withstand the impact of the event and is related with livelihoods, while resiliencies defined as the ability to cope with or adapt to the hazard stress through preparedness and spontaneous adaption once the event has manifested itself.

A similar approach which links vulnerability to resistance and resilience is introduced by Bogardi (2006). In this approach, the two terms of resistance and resilience are contrasted in that resistance relates the capacity of the system to *remain unchanged* for an interval of time after the event has manifested itself, while resilience is related the capacity of the system to *recover* to its state prior to the disaster. Rose (2004) has developed measures of resilience that distinguish between what he terms *inherent* and *adaptive* resilience. Inherent resilience refers to characteristics of different social units (households, businesses, communities, local economies) that serve as sources of strength when the social order is disrupted. For households, for example, inherent resilience may be based on household income, savings, and other sources of wealth, as well as household disaster plans. For businesses, inherent resilience may be rooted in large corporate assets, market diversification, and pre-event mutual aid agreements. For communities, indicators of inherent resilience can include extensive pre-event collaborative preparedness efforts and the existence of rich networks of community-based organizations. Adaptive resilience, which is manifested when a disaster event occurs, refers to the capacity of social units to overcome crisis-related problems through effort and ingenuity. Communities facing disasters must find substitutes for resources that are destroyed or are no longer available; identify and mobilize personnel, material, and financial resources; and exercise creativity in areas in which plans fall short.

Within all of these disciplinary areas, the challenge is often the quantitative representation of not directly measurable aspects of vulnerability or resilience contained in the different theoretical frameworks. This topic, known as operationalizing vulnerability, is a central focus of cross-disciplinary research, and is critical for translating conceptual frameworks into practical tools that can be used for communication and risk management. Indicator-based approaches constitute a transparent possibility in providing an operational representation (of not directly measurable conditions) regarding the susceptibility, coping capacity and resilience of a system to disaster impacts (Jäger, 2002; Gallopin 1997a; Cutter et al., 2003). In indicator-based approaches, often theoretical vulnerability frameworks provide the basis for the selection and combination of vulnerability indicators and sub-indicators. Indicators also enable a comparative analysis of vulnerability and have been used increasingly to rank vulnerability across regions, countries, and populations with the objective of aiding governmental bodies and other organizations in the allocation of resources for vulnerability reduction (Cutter and Finch, 2008). In recent years, numerous indicator-based approaches at various scales and contexts have emerged. Some widely cited indicator frameworks include, the Disaster Resilience Index by Cutter et al., (2010); Social Vulnerability Index by Cutter et al., (2003); Urban Seismic Risk by Carreño et al., (2007); Disaster Deficit Index by Cardona et al., 2004; Disaster Risk Index of the UNDP by Peduzzi et al., 2009; and the World Bank Hotspots indexing project by Dilley et al., (2004. However, little is known about the reliability and validity of these indices, especially when applied towards a global comparison of cities or regions to vulnerability from hazards.

Social vulnerability indicators are defined in the literature as descriptors of a person or group and the processes that influence their capacity to anticipate, cope with, resist and recover from the differential impact of natural hazard (Burton et al. 1978; Mitchell et al. 1989; Cutter et al. 2003; Wisner et al. 2004). Social vulnerability in the context described here is related to the differential vulnerability created by social inequalities, lack of access to resources and the absence of institutional and community organization. In particular, social vulnerability parameters that impact a community’s recovery from potential negative consequences of industrial losses can be related to the inherent fragilities of that community (personal attributes, employment situations, finances). At the same time, the capacity to absorb the adverse effects of industrial losses in a given geographical area can also be related to the measure of coping capacities in a society (infrastructure and services, capital, savings and other buffers and resources for recovery of livelihoods). The work performed by Susan Cutter (Cutter et al., 2008) in developing a GIS-based Social Vulnerability Index (SoVI) for the continental United States represent some of the latest advancements in a hazard based social vulnerability index that is derived and validated using statistical methods. At the same time hazard-based social vulnerability and coping capacity indicator systems for local and regional level implementation have been developed by KIT researchers (Khazai et al., 2011; Daniell et al., 2010a) and validated with stakeholders in urban agglomerates such as Istanbul, Metro Manila and Mumbai (Khazai et al., 2009; Fernandez et al. 2006; and Khazai et al., 2011). The core of the research effort in SYNER-G is to draw on and harmonize the various international initiatives and establish an analytical framework that is methodologically robust and generalizable for constructing, evaluating and validating complex indicators of socio-economic vulnerability which will be coupled with direct risk indicators.

2.1.2 Shelter and housing models

Most Earthquake Loss Estimation software providing input for shelter needs are based on the HAZUS methodology (Harrald and Al-Hajj, 1992; ABAG 2000), which calculates displaced and shelter-seeking populations as a function of structural damage to buildings. However, shelter use is also influenced by other factors. The decision to utilize public shelter is correlated with a variety of social and demographic factors (Tierney et al, 2001). MAEViz adapts and extends the HAZUS methodology for shelter demand by taking into account shelter needs arising from the loss of water and/or electric power. New approaches have recently been developed (and currently are under development) which simulates households' decision-making and considers socio-economic, temporal and spatial factors in addition to housing damage and lifeline loss to estimate displaced and shelter seeking populations (Chang et al., 2009; Wright and Johnston, 2010; Khazai et al., 2011). For example, the model by Chang et al. (2009) adopts an agent-based approach that utilizes census microdata on households and simulates households' decision-making about post-earthquake shelter on the basis of their dwelling condition, risk perception, mobility, and resources. These models have been developed for the North American, European and New Zealand contexts and implemented in cities such as Los Angeles and Wellington. Other methods have focused on deriving post-disaster shelter information from multi-temporal remotely-sensed data, applied to monitor and evaluate recovery efforts in Thailand and Pakistan (Saito et al., 2009).

2.1.3 Health and health-care systems models

From the perspective of societal impacts, the interest in measuring impact on health and healthcare systems is to provide estimates of **earthquake-related deaths and injuries** and capture the **performance of healthcare systems** in terms of providing post-event health care services. Casualty estimation methodologies (Coburn and Spence 2002; FEMA 2008) in ELE software provide estimates of both injuries and fatalities, which can assist planners in determining the resources required to deal with increased surge in patients. These methodologies generally exclude casualties due to secondary causes, and do not account for injuries that can worsen and even become fatal as a result of systemic failures of healthcare systems and parallel infrastructure (e.g., transport, power, etc.). Systemic failures in healthcare delivery and lack of access to food and shelter can also lead to the exaggeration of baseline diseases and increased transmission of communicable infectious diseases. Several researchers, have proposed methods, to assess interrelated systems - structural, non-structural, lifelines, and personnel - according to performance levels indicating functionality (Holmes and Burkett, 2006; Chang, 2008; Lupoi et al., 2008; Yavari et al. 2010).

2.1.4 Urban recovery models

Attention to measuring, monitoring, and modelling urban disaster recovery has been increasing in recent years. Progress is being made in developing a theory of recovery (see recoverytheory.net). Guidelines and methods for quantitatively measuring and monitoring earthquake recovery have been proposed and tested by consortium members, using statistical data (Karatani and Hayashi, 2007; Chang, 2010), remote sensing data (Bevington et al., 2011; Brown et al., 2008; Brown et al., 2011), and structured interview data (Hill et al., 2011). Case applications include major earthquakes and/or tsunami in Japan, Thailand, Pakistan, and Haiti. At the same time, studies of recovery in major North American hurricanes (Andrew, Charley, Katrina, Rita) have yielded further insights on temporal trends (e.g., in housing reconstruction and population), as well as spatial differentials in recovery within a disaster-affected urban area (Smith and McCarty 1996; Plyer and Bonaguro, 2007; Hori et al., 2009; Finch et al., 2010). Modelling recovery remains very challenging, due to the multiplicity of factors that influence recovery and the complexity of their interactions. One of the critical challenges concerns the need to take into account pre-disaster trends and post-disaster decisions, both of which strongly influence recovery outcomes. Yet, models are needed to help planners and decision-makers to understand, anticipate, and facilitate recovery (Olshansky and Chang, 2009). Prototype models of urban disaster recovery have been developed by Miles and Chang (2006, 2007, in press) and applied to the Kobe and Northridge earthquakes.

2.2 ECONOMIC IMPACT ASSESSMENT

Economic impacts from earthquakes were not considered in the modelling approaches developed in SYNER-G due to limitation of resources. Nevertheless, a brief review of economic impact models is included here. Economic effects are usually grouped into three categories: direct, indirect, and macroeconomic effects. Two basic types of analyses are used to assess the economic effects of disasters: top-down, and bottom-up modelling approaches. The top-down approach, which is based on macroeconomic and mesoeconomic analysis, characterizes the national or regional economy as being composed of interacting economic sectors. Existing macroeconomic or top-down approaches utilize several types of models, including Input-Output (I-O) and Computable General Equilibrium (CGE) models, economic growth frameworks and simultaneous-equation econometric models (e.g. Yezer and Rubin, 1987; Ellson et al., 1984; West and Lenze, 1994; Brookshire et al., 1997; Chang et al., 1997; Guimaraes et al., 1993; Rose 2007; Okuyama, 2007; Hallegatte and Ghil, 2008; Hallegatte, 2008; Freeman et al., 2002; Mechler, 2004; Mechler et al., 2010; Hochrainer, 2006).

The bottom-up approach, which aims at evaluating actual impacts or risks on consumers' willingness to pay (alternatively, willingness to accept) is based on microeconomics. It can scale up local level data to an aggregate estimate of disaster costs (Van der Veen, 2004). Such approaches measure direct property damage as well as business interruption costs, health impacts and reductions in wellbeing, and sometimes impacts on ecosystem services. Rather than running numerical models, the focus of work in the microeconomics of disaster risk has been on empirical and statistical analysis and understanding households' and firms' decisions to (often not) invest in risk reduction (Kunreuther, 1996). One focus area has been on insurance-related applications. As well, decision-analytical methods employing Cost-Benefit Analysis (CBA) and other tools have been used to gauge the net benefits of prevention. There is an emerging literature on the use of CBA and other appraisal methods to pro- actively evaluate risk-reduction investments, but there are fewer, real-world applications, particularly in a developing country context and taking a probabilistic perspective (Benson and Twigg, 2004; Smyth et al., 2004; Mechler, 2005; Ghesquiere et al., 2006; MMC, 2008; Hochrainer et al., 2010).

3 Framework for integration of physical and socio-economic models

3.1 INTEGRATED PHYSICAL AND SOCIAL LOSS MODELS

Fig. 3.1 shows three possible entry points for socio-economic models. In SYNER-G the socio-economic models are being brought in at the second entry point depicted in Fig. 3.1. Here, new methods have been developed to compute social losses (e.g., number of displaced people and casualties) as an integrated function of hazard intensity, vulnerability of physical systems and the social vulnerability of the population at risk. In many earthquake loss estimation models socio-economic models are brought in at the third entry point as linear "damage-consequence functions" for the estimation of direct social and economic losses from physical system parameters, such as, level of building damage. Bringing in socio-economic models at the first entry point shown in Fig. 3.1 as empirical models, requires the systematic collection of post-event social and economic post-earthquake data which is typically not feasible, given the perishable nature of such data and that it is currently not being collected in a systematic and coordinated fashion.

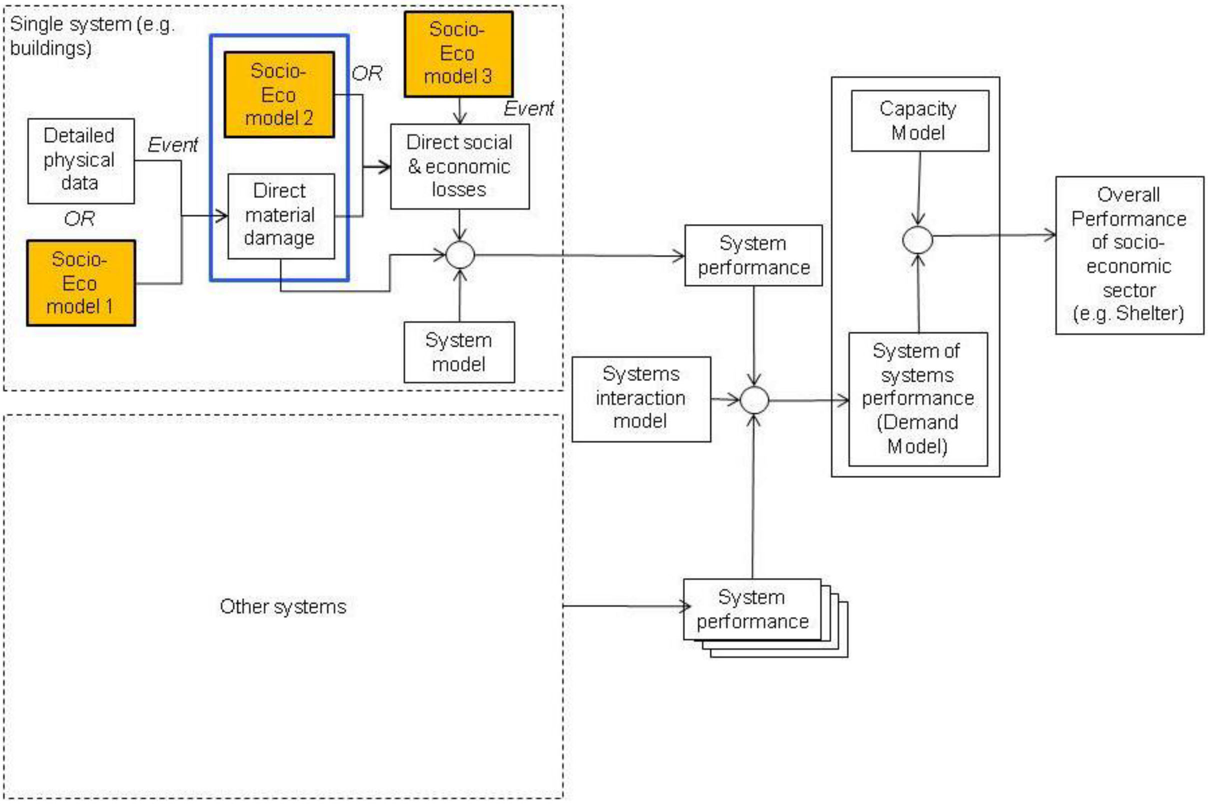

Fig. 3.1 Possible interaction of socio-economic models with physical vulnerability/loss estimation models

Contributing to the challenge of integrating social vulnerability with physical damage/performance models is the fact that social vulnerability is a fundamentally relative phenomenon and not something that can be directly observed and measured. Thus, one of the main objectives has been the adoption of an indicator system and common nomenclature which posits social vulnerability in relational terms with respect to both shelter and healthcare systems. Consequently, transparent and validated indicator systems, which characterize the human, institutional and functional vulnerability (and resilience) of the system have been defined.

An approach for combining physical system and social vulnerability models and a framework to analyze the impact in the two sectors of shelter and health is developed in SYNER-G. The integrated approach developed here assumes that a triggering hazard event has occurred, and provides a framework to link the degree of damage and performance of physical systems to vulnerabilities and coping capacities in society to assess: (1) Impacts on displaced populations and their shelter needs, and (2) Health impacts on exposed populations and their health-care needs. This way of conceptualizing the integrated framework emphasizes the importance of understanding the interrelations between physical and social systems. In other words, how direct physical losses can potentially aggravate existing vulnerabilities in society and how vulnerabilities in society can ultimately lead to greater impacts from physical damage and losses.

One of the first requirements in operationalizing any vulnerability framework is developing a metric for measuring vulnerability and establishing a spatial scale (unit) for its comparison. The indicator framework developed here is harmonized based on the *Sub-city District (SCD)* subdivision of the **European Urban Audit** which is the only available European-wide administrative geographical database.

The framework also takes into account that vulnerability factors vary among the different sectors addressed here (i.e., shelter, health, transportation). In the framework design it is assumed that interactive and causal processes take place between society and the physical systems it interacts with. For example, the loss of building habitability (derived from physical models) will play a major role in the decision to evacuate one's domicile and seek public shelter. Here the interaction between building habitability and social factors such as the occupants tenure status (home owner vs. renter), whether the occupant lives in a single family home or a multi-family apartment structure, the level of anxiety of aftershocks, etc., will ultimately determine the resistance to evacuate the building. As a demonstration of the prototype methodology, the results of the integrated framework are applied in a pilot case study in L'Aquila, Istanbul and Thessaloniki (shelter), 12 European Cities (health) and Thessaloniki city (transportation accessibility, shelter and health), in order to obtain a ranking of transportation accessibility, shelter needs and health impact of different cities or districts in these cities. The ranking can answer the question, which of two affected city districts will require more resources to better absorb the health impacts or shelter demand from an earthquake.

3.2 INTEGRATED EVALUATION OF PHYSICAL AND SOCIO-ECONOMIC MODELS

The goal of the general methodology developed within the SYNER-G project is to assess the seismic vulnerability of an Infrastructure of urban/regional extension, accounting for all relevant and meaningful inter- and intra-dependencies among infrastructural components, as well as of uncertainties. The model for the Infrastructure actually consists of two sets of models that form a sequence. The first set consists of the physical models of the systems making up the Infrastructure. These models take as an input the hazards and provide as an output the state of physical/functional damage of the Infrastructure. The second set of models consists of the socio-economic models that take as an input the output of the physical models and provide the socio-economic consequences of the event. Within the SYNER-G project the physical models are developed in WP3 and WP5 (see Reference Report 1 (Pinto et al., 2012) for detailed descriptions of the methodologies), while socio-economic models are developed in WP4. The SYNER-G methodology integrates these models in a unified analysis procedure.

For the two socio-economic models studied within the socio-economic impact analysis in SYNER-G -the Shelter and the Healthcare model in WP4)-, Fig. 3.2 illustrates the integrated procedure that leads from the hazard to the evaluation of the demands on the shelter and health-care system, leading to the computation of two key parameters: Displaced Population (DP) and Casualties.

In particular, Fig. 3.2 shows how the Environment acts upon the Infrastructure through the Hazards. These induce in the components of all Infrastructural systems a certain level of Physical damage. In the figure, this is represented in terms of damage to buildings (Bldg damage) and damage to lifelines (Utility loss)[1]. The level of induced physical damage depends not only on the hazard but also on the fragility, a function of Building Typology for the buildings. To compute both casualties and displaced population the occupancy level of the buildings (Bldg occupancy) is used as a first input. Building occupancy in turn depends on the typology, the total Built-up area, the Population, the building Usage and the Time of the day. The population at risk of being displaced is computed from the building occupancy and habitability of buildings at the time of the event (Bldg Habitability). Building Habitability in turn depends upon the state of usability of buildings (Bldg usability), whether the buildings are still served by fundamental utilities, and also on the Weather conditions. Casualties are obtained as the number of deaths and injured by combining building occupancy, building damage, building typology and casualty ratios (see methodology in following section for computing displaced population and casualties).

The number of casualties and displaced persons are inputs into a multi-criteria utility model to determine health impacts and shelter needs.

Fig. 3.2 also shows how the required input information is usually contained in three distinct data bases maintained by different sources. In Europe, a harmonized source for physical

[1] Details of the evaluation of the physical and functional consequences of the hazards on buildings and utility networks are not the focus of this Reference Report and can be found in SYNER-G Reference Report 1.

data on the buildings and socio-economic data on urban areas, in the form of the Building Census and European Urban Audit, respectively, is EUROSTAT. The information on usage is usually provided in the form of a Land Use Plan, maintained from a local source (the Municipality).

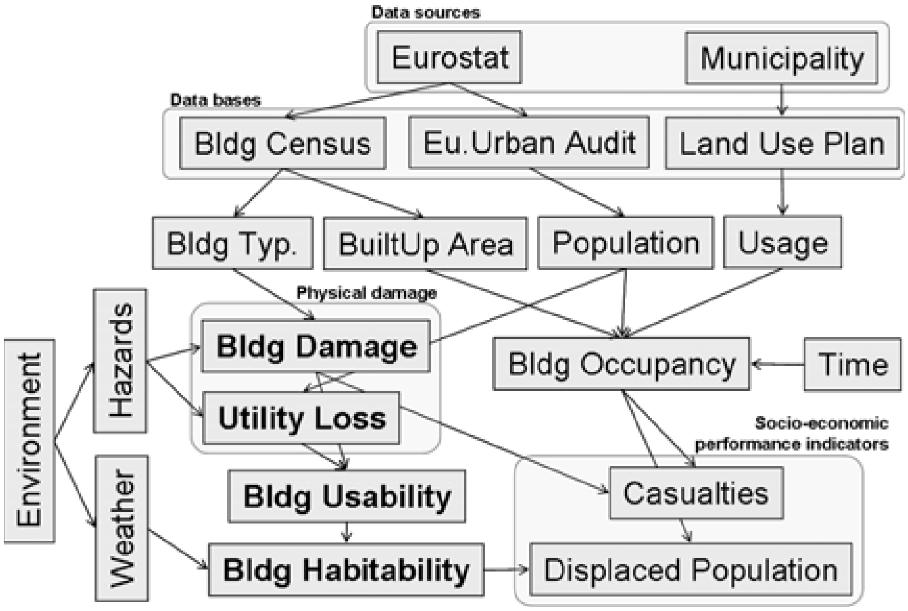

Fig. 3.2 Integrated evaluation of physical and socio-economic performance indicators

3.3 MULTI-CRITERIA DECISION ANALYSIS FRAMEWORK

The socio-economic models for estimating shelter needs and health impact interface with the output performance indicators, Casualties and Displaced Population, shown in Fig. 3.2. The integrated socio-economic models developed in SYNER-G are based on the principles of multi-criteria decision theory (MCDA) which allow the bringing together of different competing criteria; for example, in the case of the shelter model, these are both parameters influencing displacement due the physical inhabitability of buildings, as well as social vulnerability (and coping capacity) factors of the at-risk population influencing their decision to evacuate and seek shelter. The resulting framework is also implemented in a software system based on multi-criteria decision theory (MCDA) with a dynamic interface to take into account a broader range of expert judgement. The goal here is to demonstrate how such a framework can be used as a communication tool for decision makers in disaster risk management through the interactive modelling of indicator weights or complementing the existing system of indicators with additional available data (e.g., for the assessment of additional vulnerability dimensions).

The theoretical framework for integration of physical and social performance indicators is founded on the work of Cardona et al. (2005), and provides an overview of not only the expected direct damages, but also the potential for aggravating impact of the direct damages by the social fragility and lack of resilience of the different sectors analyzed here. As shown in Fig. 3.4 a physical performance index is obtained, for each unit of analysis by interacting with the physical infrastructure models, whereas the total social impact index is obtained by multiplying the direct physical performance indices by an indirect impact factor, based on variables associated with the socio-economic conditions of each unit of analysis. In order to reduce the complexity of the total system for applied purposes, vulnerability in each system is operationalized by a set of discrete indicators, representing social vulnerability and coping capacities.

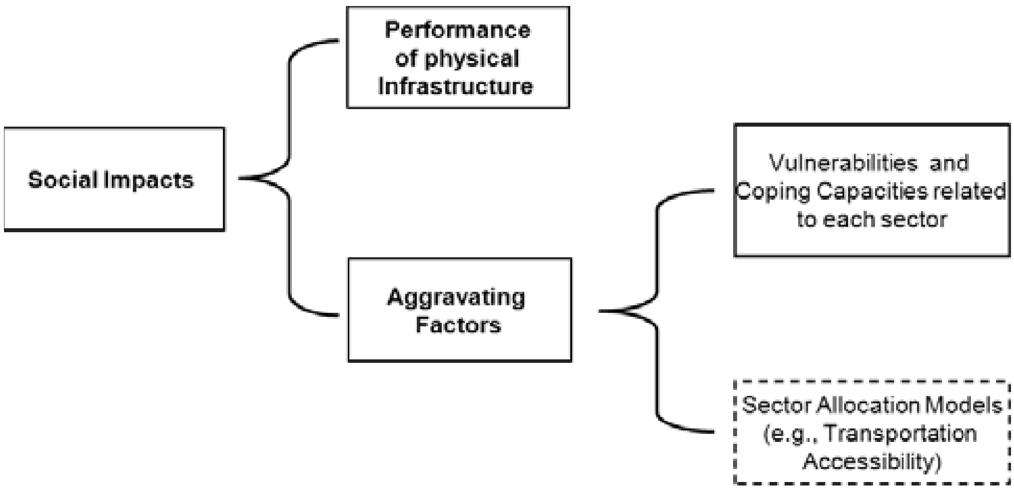

Fig. 3.3 Structure of the integrated framework for assessment of social impacts

The process of developing an integrated indicator framework for assessment of overall social impacts as outlined in Fig. 3.4 consists of five main steps which should be passed in an iterative manner (Nardo et al., 2005). These development steps are very similar to the main phases of the multi-criteria decision theory (MCDA) or multi-attribute-value theory (MAVT). Therefore, for the development of a hierarchical indicator framework the methodological approaches used within a MAVT-Analysis can be transferred to the vulnerability assessment applied here.

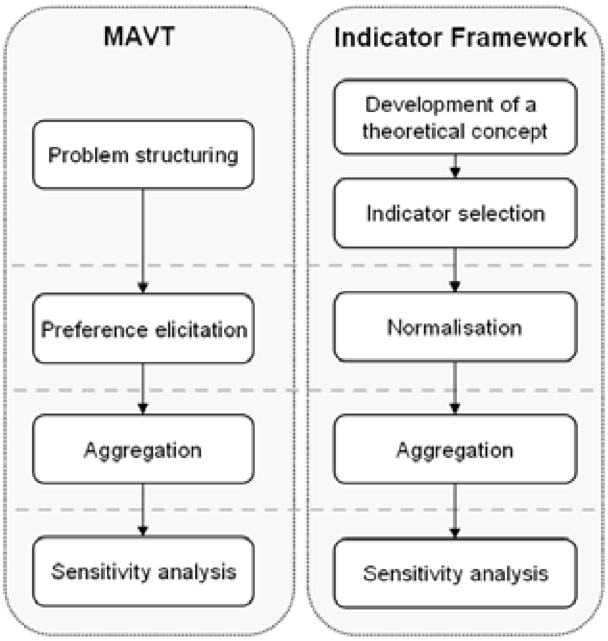

Fig. 3.4 Methodological steps of the development of a hierarchical indicator framework

Similar to the problem structuring step of a MAVT-Analysis, within the indicator development process the development of the theoretical indicator framework (step 1) contains the specification of the dimensions to be covered, i.e. the sub-systems for each defined sector as well as the spatial scale of assessment.

The second methodological step is defining and populating the indicators for each sub-system for operationalizing the theoretical vulnerability framework and quantifying disaster vulnerability. In order to guarantee the quality of the composite indicator framework, the single sub-indicators should meet some quality standards. For example, indicators used should be reliable, accessible, reproducible, interpretable and accurate (Birkmann, 2006).

The indicators and sub-indicators have been chosen according to the vulnerability factors and decision criteria identified for each system, i.e. for shelter needs (see Khazai et al., 2011 Deliverable 4.1); health impacts (see Khazai et al., 2012); and transportation accessibility (see Düzgün and Kavanc., 2011). They have been harmonized at the European level based on data available from the EUROSTAT Urban Audit. The indicator framework defined for the analysis of Shelter needs and Health impacts is presented later in Chapter 6 and 7 respectively.

Before aggregating the values of the sub-indicators into an overall composite indicator value, the sub-indicator values must be normalized. This is necessary because most of the sub-indicators have different units and cannot be combined into the indicator framework in their original values. Furthermore, the normalization enables the integration of quantitative and qualitative sub-indicators within the same framework. Within this third step of the framework the values of all sub-indicators are depicted on a scale between 0 and 1 using value functions. Here, 0 stands for low vulnerability values and 1 for a high degree of vulnerability. For the normalization process, both linear and S-shaped transformation functions are used. The software tool for in which the methodology has been implemented facilitates the selection of value functions and the calculation of standardized indicator values.

In the next step, the overall vulnerability value of the analysed sectors is calculated, aggregating the values of the weighted single sub-indicators using both a standard **additive formula** as well as **multiplicative aggregation formulas** (Fig. 3.5). In the additive aggregation, an especially important aspect for the quality of results of the integrated indicator system is marked by the assignment of weights for the individual indicators, and offsetting them against each other such that:

$$w_i \geq 0 \quad \text{and} \quad \sum_{i=1}^{n} w_i = 1 \tag{3.1}$$

In this framework the weights, w_i, express the contribution to the overall social impacts as the relative individual importance of sub-indicators. The elicitation of weights requires a deeper understanding of the vulnerability criteria in each of the sectors. Therefore, the retrieval of importance-weights is ideally done based on an in-depth review of the literature and/or in participatory workshops with experts from emergency management and disaster science. Weights can also be developed based on statistical analysis of the data and understanding the contribution of each indicator in terms of describing the variance in the data (see Chapter 4). Within hierarchical indicator frameworks (due to the use of the simple additive aggregation rule) dependencies and correlations among the various indicators may also lead to an over- or underestimation of single indicators or an entire indicator-dimension.

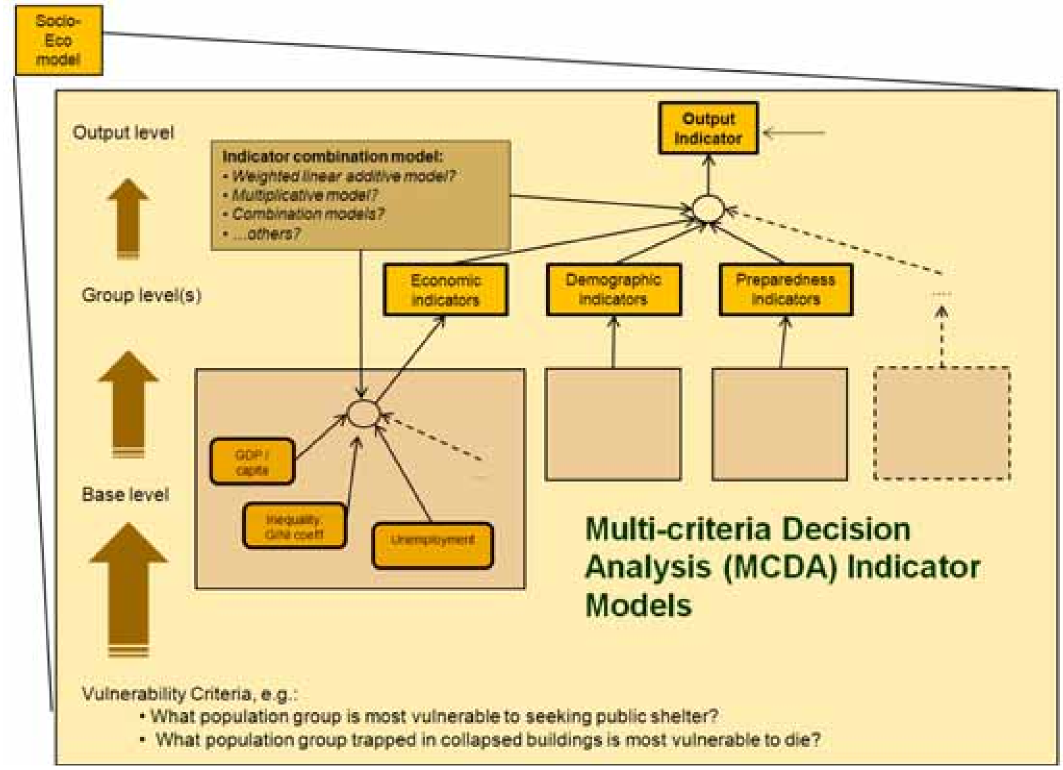

Fig. 3.5 Generalized schematic showing the aggregation of sub-indicators using both multiplicative and additive formulas to arrive at composite and output indicators

4 Harmonization of socio-economic data for Europe

4.1 INTRODUCTION AND BACKGROUND

4.1.1 Background

The methods proposed in estimating socio-economic impacts within SYNER-G are developed for the urban and sub-regional spatial scale of analysis. To operationalize the shelter needs and health impact models for European level implementation at this scale, the EUROSTAT Urban Audit data has been analysed. The Urban Audit database is the only European-wide database that has assembled socio-economic indicators at the urban scale of analysis for a balanced and representative sample of cities in Europe. Data in the Urban Audit was collected for four different spatial scales:

- The first of these is the "central" or "core city", i.e. the administrative unit, for which a rich dataset is generally available.
- Secondly, the larger urban zone (LUZ) - covers the "hinterland" of the city.
- Thirdly, inter-urban discrepancies gathering data for sub-city districts (SCD).
- Finally, for Paris and London, a "kernel" was created in order to facilitate comparisons between these two big cities.

After a "pilot"- Urban Audit in 1999, the first full-scale European Urban Audit took place in 2003 for an initial 15 countries of the European Union. In 2004, the project was extended to the 10 new Member States plus Bulgaria, Romania and Turkey (25 EU countries). For the 2003/2004 data collection exercise, 336 variables were collected, covering most aspects of urban life. The second full-scale Urban Audit took place between 2006 and 2007, and involved 321 European cities in the 27 countries of the European Union, along with 36 additional cities in Norway, Switzerland and Turkey. A collection of urban statistics has started in 2009 and includes small changes to the lists of variables and cities compared to 2006. 329 variables were collected for 323 European Union cities and 47 cities in Norway, Switzerland, Turkey and Croatia. First results expected to be published in the first months of 2012 are still not available for download as of the date of this publication and were not used in this study.

To operationalize the shelter needs and health impact models for European level implementation at regional and urban scale, the *EUROSTAT Urban Audit* data has been analysed for 44 indicators collected for 7586 sub-city districts in 321 cities of 30 European countries. The Principal Component Analysis (PCA) was performed on a standardized dataset for two periods (1999-2002 and 2003-2006) in order to reduce the indicators to a set of principle components explaining most of the variation in the data (*see Vangelsten et al., 2011).* The Urban Audit indicators were related to the vulnerability criteria of the systemic shelter model and validated with empirical data and expert surveys for the L'Aquila earthquake *(see Khazai et al., 2012 and Elefante et al., 2012)*.

Table 4.1 Domains covered in the Urban Audit Database

1. Demography	**6. Environment**
1.1 Population	6.1 Climate/Geography
1.2 Nationality	6.2 Air quality and noise
1.3 Household structure	6.3 Water
2. Social aspects	6.4 Waste management
2.1 Housing	6.5 Land use
2.2 Health	**7. Travel and transport**
2.3 Crime	7.1 Travel patterns
3. Economic aspects	**8. Information Society**
3.1 Labour market	8.1 Users and infrastructure
3.2 Economic activity	8.2 Local e-government
3.3 Income disparities and poverty	8.3 ICT sector
4. Civic involvement	**9. Culture and recreation**
4.1 Civic involvement	9.1 Culture and recreation
4.2 Local administration	9.2 Tourism
5. Training and training provision	
5.1 Education and training provision	
5.2 Educational qualifications	

4.1.2 Principal component analysis – a brief introduction

Principal component analysis (PCA) is a technique to analyse data consisting of multiple observations of a set of variables. PCA calculates inter-correlation between variables and a new set of transformed variables are created where the importance of each of the new variables in terms of the variability of the data is identified. Granted that the original data fulfil the requirement of multivariate normal distribution, the transformed variables are all statistically independent. Even for data that are not multivariate normally distributed, Jolliffe (2002) states that PCA can be very useful to understand the structure of the data.

In the preface, Jolliffe (2002) states:

”*Principal component analysis is probably the oldest and best known of the techniques of multivariate analysis. It was first introduced by Pearson (1901), and developed independently by Hotelling (1933).*

The central idea of principal component analysis (PCA) is to reduce the dimensionality of a data set consisting of a large number of interrelated variables, while retaining as much as possible of the variation present in the data set. This is achieved by transforming to a new set of variables, the principal components (PCs), which are uncorrelated, and which are ordered so that the first <u>few</u> retain most of the variation present in <u>all</u> of the original variables. Computation of the principal components reduces to the solution of an eigenvalue-eigenvector problem for a positive-semi-definite symmetric matrix.”

Several different methodological formulations are available for how to perform a PCA. In the PCA tutorial from 2002, Smith, describes a six step procedure:

1. Collect and organize data
2. Subtract the mean
3. Calculate the covariance matrix
4. Calculate the eigenvectors and eigenvalues of the covariance matrix
5. Choose principal components and form a feature vector
6. Derive the new data set

The purpose of analysing the European Urban Audit data using PCA is to

- identify correlation between indicators
- exclude indicators that have no or poor data, or have little variation
- identify which indicators are key to create socio-economic profiles of European urban areas

In the following, the format and content of the Urban Audit raw data will be presented in more detail. Section 4.2 presents the necessary pre-processing of the data before the results from the Principal Component Analysis are given in Section 4.3. Section 4.4 summarizes and gives recommendations.

4.2 DESCRIPTION OF RAW DATA

4.2.1 Data source

The Statistical Office of the European Communities, Eurostat, offers a huge range of data across the 27 member states. (Eurostat[2]). From national to local scale they cover the topics of general and regional statistics, economy and finance, population and social conditions, industry, trade and services, agriculture and fisheries, external trade, transport, environment and energy, and science and technology. Statistics of social conditions are very broad covering information about demographics, health, education and training, labour market, income, social inclusion and living conditions, social protection, household budget, crime and criminal justice, and cultural aspects (European Commission 2010). Most of the Eurostat data are provided on levels describing nations, greater regions to large cities. These scales are too small for the purpose of shelter needs estimations after disasters, requiring the sub- city district scale for reliable outcome and precise located needs estimations.

Urban Audit focuses on city scale, where data are collected on three levels: The core cities, larger urban zones (LUZ) including the hinterlands, and sub- city- districts (SCD) gathering inters- urban discrepancies. Information is covered over nine categories: Demography, Social Aspects, Economic Aspects, Civic Involvement, Training and Education, Environment, Travel and Transport, Information Society, and Culture and Recreation. Eurostat is responsible for coordinating the flow of Urban Audit (European

[2] http://epp.eurostat.ec.europa.eu/portal/page/portal/region_cities/city_urban/urban_audit_data_collections

Commission 2010). Fig. 4.1 shows a map of the participating cities. The results of the latest 2009 – 2011 data collection are not yet published thus the model refers to previous data sets. The Urban Audit data are freely accessible from Eurostat. Data on SCD scale are most preferable.

The full list of variables used for the creation of indicators is provided in **Error! eference source not found.**. Only data on SCD level are considered within the model, and listed in the tables. Information on this scale are available about the population size, density, and sex and age distribution, mortality, the residents origin, number of households and household size, housing quality, crime rate, unemployment rate, household income, social security benefiters, education status, and the green space area (European Commission 2010).

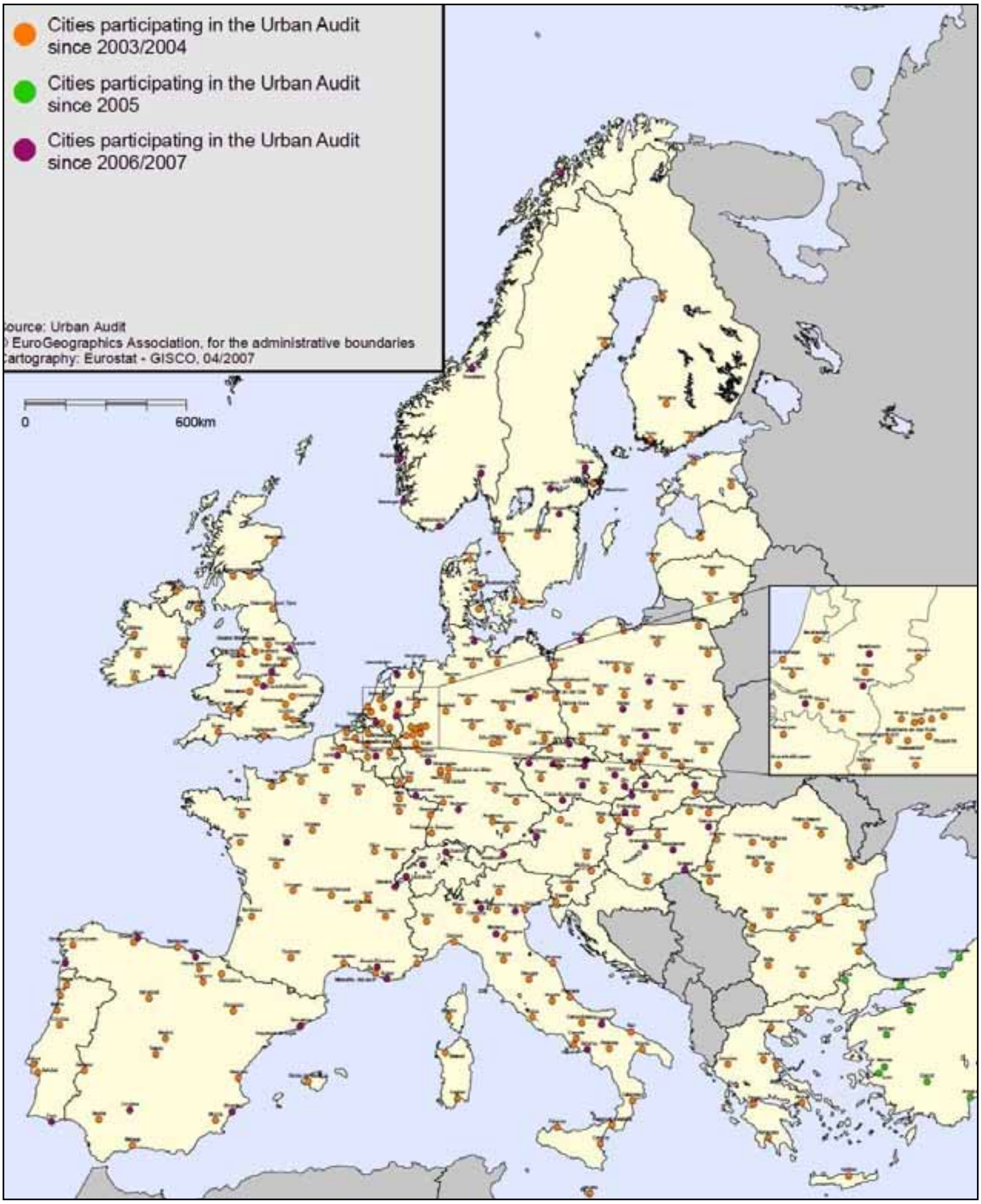

Fig. 4.1 Map of Urban Audit City Participants

Table 4.2 Compilation of Urban Audit Indicators, available on Sub-City-District. Highlighted are the indicators being most available over the districts. Sources: European Commission 2010, p. 228-231)

	List of Urban Audit Indicators			
	Code	Label	Numerator	Denominator
Demography	DE1001I	* Total resident population	DE1001V	-
	DE1040I	Proportion of total population aged 0-4	DE1040V	DE1001V
	DE1003I	*Proportion of females to males in total population	DE1003V	DE1002V
	DE1061I	Total population change over 1 year	DE1001V (t)	DE1001V (t-1)
	DE1062I	* Total annual population change over 5 approx.years	DE1001V (t)	DE1001V (t-n)
	DE2005I	* Proportion of Residents who are not EU Nationals and citizens of a country with high HDI	DE2005V	DE1001V
	DE2006I	* Proportion of Residents who are not EU Nationals and citizens of a country with a medium or low HDI	DE2006V	DE1001V
	DE3003I	* Total number of households	DE3001V	-
	DE3004I	* Average size of households	DE3017V	DE3001V
	DE3002I	* Proportion of households that are 1-person households	DE3002V	DE3001V
	DE3005I	* Prop. of households that are lone-parent households	DE3005V	DE3001V
	DE3008I	* Prop. households that are lone-pensioner households	DE3008V	DE3001V
Social Aspects	SA1001I	* Number of dwellings	SA1001V	-
	SA1018I	* Proportion of dwellings lacking basic amenities	SA1018V	SA1001V
	SA1012I	* Proportion of households living in social housing	SA1012V	DE3001V
	SA2029I	Crude death rate per 1000 residents	SA2019V*1000	DE1001V
	SA2030I	Crude death rate of male residents per 1000 male residents	SA2020V*1000	DE1002V
	SA2031I	Crude death rate of female residents per 1000 female residents	SA2021V*1000	DE1003V
	SA2019I	Total deaths per year	SA2019V	
	SA2016I	Mortality rate for <65 per year	SA2016V	DE1040V + DE1043V + DE1046V + DE1052V + DE1025V
	SA3001I	* Total Number of recorded crimes per 1000 population	SA3001V*1000	DE1001V
mic Aspect	EC1201I	Annual average change in employment over approx. 5 years	EC1001V(t)-EC1001V(t-n)	EC1001V -EC1001V(t-n)
	EC1010I	Number of unemployed	EC1010V	-

	EC1020I	* Unemployment rate	EC1010V	EC1001V
	EC1148I	Proportion of residents unemployed 15-24	EC1148V	EC1142V
	EC1202I	Proportion of unemployed who are under 25	EC1148V	EC1010V
	EC1005I	Net activity rate residents aged 15-64	EC1001V- EC1010V	DE1046V + DE1049V + DE1052V + DE1025V
	EC1006I	Net activity rate residents aged 15-24	EC1142V- EC1148V	DE1046V + DE1049V
	EC1007I	Net activity rate residents aged 55-64	EC1145V- EC1151V	DE1025V
	EC3039I	* Median disposable annual household income (for city or NUTS 3 region)	EC3039V	-
	EC3057I	Percent. households with less than half nat.aver.income	EC3057V	EC3056V
	EC3055I	Percent. households with less than 60% of the national median annual disposable income	EC3055V	EC3056V
	EC3060I	Proportion of households reliant upon social security	EC3060V	EC3056V
	EC3063I	Proportion of individuals reliant on social security	EC3063V	DE1001V
Training and education	TE2025I	* Prop. of working age population qualified at level 1 or 2 ISCED	TE2025V	DE1046V + DE1049V + DE1052V + DE1025V
	TE2028I	Prop. of working age population qualified at level 3 or 4 ISCED	TE2028V	DE1046V + DE1049V + DE1052V + DE1025V
	TE2031I	Prop. of working age population qualified at level 5 or 6 ISCED	TE2031V	DE1046V + DE1049V + DE1052V + DE1025V
Environment	EN5003I	* Total land area (km2) -according to cadastral register	EN5003V	-
	EN5001I	Green space (in m2) to which the public has access per capita	EN5001V*10000	DE1001V
	EN5012I	* Proportion of the area in green space	EN5012V	EN5003V
	EN5101I	* Population density: total resident pop. per square km	DE1001V	EN5003V
	TOTAL	**41 Indicators in 5 categories on SCD level**		

4.2.2 Indicators and sampled districts

In the downloaded Urban Audit data set, a total of 958 indicators are listed grouped as follows:

- Demography (DE)
- Economic aspects (EC)
- Environment (EN)
- Social aspects (SE)
- Training and education (TE)

Out of the 958 indicators, data are collected for only 44 indicators. Data has been collected for two periods, 1999-2002 and 2003-2006. During the first period, data has been collected for 7856 districts in 321 cities in 30 European countries. During the second period, data has been collected for 2972 districts in 173 cities in 24 European Countries.

4.2.3 Lack of completeness

There is a lot of missing data in the data set. No district has data for all 44 indicators, and no indicator has been collected for all districts. Organising the data into a matrix with indicator as column heading and district as row heading, only 32 % of the matrix is filled for the 1999-2002 period and 35% for 2003-2006. To arrive at a data set with reasonable completeness for analysis purposes, while keeping an appropriate mix of indicators and geographical country/city spread, requires a careful selection of indicators and districts.

4.3 ANALYSIS OF 2003-2006 DATA

The initial selection of indicators for the 2003-2006 analysis is based on subjective expert opinion, considering which indicators are more relevant for socio-economic vulnerability to earthquakes, in particular needs and capacity for emergency health care and public emergency shelter. **Error! Reference source not found.** shows the results from the election process. Parameters considered to be of high and medium relevance are given the values “H” and “M” respectively in the column labelled “Priority”. The two last columns are checked for the parameters believed to be relevant for the Shelter and Health models respectively. All parameters listed in the table are Urban Audit *Indicators*, except the last three which are Urban Audit *Variables*. *Indicators*, as defined in the Urban Audit, are parameters calculated from other Indicators or Variables. A *Variable* is a parameter that is directly given by the collected data. From the 2003-2006 Urban Audit data, 29 are believed to be relevant for the Shelter and Health models and are listed in **Error! Reference source ot found.**.

As not all data is available at sub-city level, analyses have been carried out at both city and sub-city level. The number of different parameters included in each of the four analyses (PCA and correlation analysis for both city level and sub-city level) are also shown in **Error! eference source not found.**.

Table 4.3 Selected indicators for PCA

No.	Indicator Code and Description
1	DE1003I: Proportion of females to males in total population
2	SA2019I: Total deaths per year
3	SA2030I: Crude death rate of male residents per 1000 male residents
4	SA2031I: Crude death rate of female residents per 1000 female residents
5	SA2016I: Mortality rate for <65 per year
6	DE1040I: Proportion of total population aged 0-4
7	SA2029I: Crude death rate per 1000 residents
8	DE1028V: Total Resident Population 65-74
9	DE1055V: Total Resident Population 75 and over
10	EN5101I: Population density: total resident pop. per square km
11	SA3001I: Total Number of recorded crimes per 1000 population
12	DE3003I: Total number of households
13	EC1020I: Unemployment rate
14	TE2028I: Prop. of working age population qualified at level 3 or 4 ISCED
15	DE2005I: Proportion of Residents who are not EU Nationals and citizens of a country with high HDI
16	DE2006I: Proportion of Residents who are not EU Nationals and citizens of a country with a medium or low HDI
17	DE3004I: Average size of households
18	TE2025I: Prop. of working age population qualified at level 1 or 2 ISCED
19	TE2031I: Prop. of working age population qualified at level 5 or 6 ISCED
20	EN5012I: Proportion of the area in green space
21	DE3005I: Prop. of households that are lone-parent households
22	EN5001I: Green space (in m2) to which the public has access per capita
23	DE3008I: Prop. households that are lone-pensioner households
24	SA1012I: Proportion of households living in social housing
25	SA1018I: Proportion of dwellings lacking basic amenities
26	EC3039I: Median disposable annual household

	income (for city or NUTS 3 region)
27	EC3060I: Proportion of households reliant upon social security
28	EC3057I: Percent. households with less than half nat.aver.income
29	EC3055I: Percent. households with less than 60% of the national median annual disposable income

Table 4.4 Indicators used in the 2003-2006 data analysis at city and sub-city level and information on expert judgment prioritization of indicators. Parameters considered to be of high and medium relevance are given the values "H" and "M" respectively in the column labelled "Priority". The two last columns are checked for the parameters believed to be relevant for the Shelter and Health models respectively.

	Code	List of Urban Audit Indicators and Variables	Parameters included in the analysis				Priority (H = high, M = medium)	Shelter (x = relevant)	Health (x = relevant)
			City level: Correlation (29)	City level: PCA (24)	Sub-City level: Correlation (24)	Sub-City level: PCA (21)			
Demography	DE1001I	Total resident population							
	DE1040I	Proportion of total population aged 0-4	x	x	x	x	H	x	x
	DE1003I	Proportion of females to males in total population	x	x	x	x	M		x
	DE1061I	Total population change over 1 year							
	DE1062I	Total annual population change over 5 approx.years							
	DE2005I	Proportion of Residents who are not EU Nationals and citizens of a country with high HDI	x	x	x	x	H	x	x
	DE2006I	Proportion of Residents who are not EU Nationals and citizens of a country with a medium or low HDI	x	x	x	x	H	x	x
	DE3003I	Total number of households	x	x	x	x	M	x	
	DE3004I	Average size of households	x	x	x	x	H	x	x
	DE3002I	Proportion of households that are 1-person households							
	DE3005I	Prop. of households that are lone-parent households	x	x	x	x	M	x	
	DE3008I	Prop. households that are lone-pensioner households	x	x	x	x	H	x	x
Social Aspects	SA1001I	Number of dwellings							
	SA1018I	Proportion of dwellings lacking basic amenities	x	x	x	x	H	x	
	SA1012I	Proportion of households living in social housing	x	x	x	x	M	x	x
	SA2029I	Crude death rate per 1000 residents	x	x	x	x	H		x
	SA2030I	Crude death rate of male residents per 1000 male residents	x	2)			H		x
	SA2031I	Crude death rate of female residents per 1000 female residents	x	2)			H		x

	SA2019I	Total deaths per year	x	[3]			H		x
	SA2016I	Mortality rate for <65 per year	x	x	x	x	H		x
	SA3001I	Total Number of recorded crimes per 1000 population	x	x	x	x	H	x	
Economic Aspects	EC1201I	Annual average change in employment over approx. 5 years							
	EC1010I	Number of unemployed							
	EC1020I	Unemployment rate	x	x	x	x	M	x	x
	EC1148I	Proportion of residents unemployed 15-24							
	EC1202I	Proportion of unemployed who are under 25							
	EC1005I	Net activity rate residents aged 15-64							
	EC1006I	Net activity rate residents aged 15-24							
	EC1007I	Net activity rate residents aged 55-64							
	EC3039I	Median disposable annual household income (for city or NUTS 3 region)	x	x	x	x	M	x	x
	EC3057I	Percent. households with less than half of the national average income	x	x	x	[7]	H	x	x
	EC3055I	Percent. households with less than 60% of the national median annual disposable income	x	[6]			H	x	x
	EC3060I	Proportion of households reliant upon social security	x	x	x	[7]	M		x
	EC3063I	Proportion of individuals reliant on social security							
Training and education	TE2025I	Prop. of working age population qualified at level 1 or 2 ISCED	x	x	x	x	H	x	x
	TE2028I	Prop. of working age population qualified at level 3 or 4 ISCED	x	x	x	x	H	x	x
	TE2031I	Prop. of working age population qualified at level 5 or 6 ISCED	x	x	x	x	H	x	x
Environment	EN5003I	Total land area (km2) -according to cadastral register							
	EN5001I	Green space (in m2) to which the public has access per capita	x	x	x	x	H	x	
	EN5012I	Proportion of the area in green space	x	x	x	x	H	x	
	EN5101I	Population density: total resident pop. per square km	x	x	x	x	H	x	x
Variables	DE1028V	Total Resident Population 65-74	x	x[1]	x[1]	[5]	H	x	x
	DE1055V	Total Resident Population 75 and over	x				H	x	x
	CI1009V	City Elections: Number of voters turned out	[4]				H	x	x

1) *The variables "DE1028V Total Resident Population 65-74" and "DE1055V Total Resident Population 75 and over" were merged in this analysis*
2) *The indicators "SA2030I Crude death rate of male residents per 1000 male residents" and "SA2031I Crude death rate of female residents per 1000 female residents" were excluded in the PCA city level analysis as they both were strongly correlated with indicator "SA2029I Crude death rate per 1000 residents" (correlation = 0.93 and 0.94 respectively)*
3) *The indicator "SA2019I Total deaths per year" was excluded from the PCA city level analysis as it correlated strongly with indicator "DE3003I Total number of households" (correlation = 0.98)*
4) *The variable "CI1009V City Elections: Number of voters turned out" was excluded from all analyzes as it contained no data both at city and sub-city level.*
5) *The two remaining Urban Audit Variables included in the study had data at city level only. No sub-city data are available*
6) *The information contained in the indicator "EC3055I Percentage households with less than 60% of the national median annual disposable income" is represented in the indicator "EC3057I Percent. households with less than half the national average income". EC3055I was therefore removed.*
7) *The indicators "EC3057I Percent. households with less than half nat. aver. income" and "EC3060I Proportion of households reliant upon social security" has no pairwise city level data with the three education indicators TE2025I, TE2028I and TE2031I. It is therefore impossible to carry out principal component analysis on these data combinations. EC3057I and EC3060I were therefore removed in the PCA Sub-City level analysis.*

4.3.1 City level analysis

The city level analysis was carried out in two stages:

1. The first phase studied correlation between all prioritised indicators and variables that had data. A total of 29 parameters were included as shown in **Error! Reference ource not found.** in the column labelled "City level: Correlation".
2. The second phase was the principal component analysis. Compared to Phase 1, four indicators were removed due to high correlation and the two variables DE1028V and DE1055 were merged into one variable counting population aged 65 and above. Thus a total of 24 parameters were included in the principal component analysis.

The off-diagonal elements in **Error! Not a valid bookmark self-reference.** show how much data can be found on each pair of indicators. Most of the data can be found for indicator pair 1 and 2 with 360 cities having corresponding data. The least data can be found for indicator pair 25 and 29 ("SA1018I: Proportion of dwellings lacking basic amenities" and "EC3055I: Percent households with less than 60% of the national median annual disposable income") with only 16 of 377 cities having collected both these indicators.

A large amount of data are missing, and this should be kept in mind when interpreting and using the results from the correlation and PCA analysis, as this significantly weakens the rigour of the results. However, it is still believed that the results can be of practical use in studying underlying structures in the societies the data covers.

For the principal component analysis it was decided to exclude some of the indicators that are well represented by other indicators. The indicators "SA2030I Crude death rate of male residents per 1000 male residents" and "SA2031I Crude death rate of female residents per 1000 female residents" were excluded as they both are strongly correlated with indicator "SA2029I Crude death rate per 1000 residents" (correlation = 0.93 and 0.94 respectively). In addition, the indicator "SA2019I Total deaths per year" was excluded as it correlates strongly with indicator "DE3003I Total number of households" (correlation = 0.98). For the principal component analysis it was also decided to merge the two variables counting elderly people into one variable:

- DE1028V: Total Resident Population 65-74
- DE1055V: Total Resident Population 75 and over

As should be expected, the two variables are highly correlated (0.96). The resulting variable counts all people aged 65 and over.

The information contained in the indicator "EC3055I Percentage households with less than 60% of the national median annual disposable income" is well represented in the indicator "EC3057I Percentage households with less than half the national average income" (correlation 0.86). EC3055I was therefore excluded in the principal component analysis. As a result, the 29 indicators used in the correlation analysis were reduced to 24 indicators for the principal component analysis. Table 4.6 lists the 24 indicators included in the principal component analysis. To assure that all indicators have zero to infinity range, all indicators measured in percent ranging from zero to hundred (a total of 14 out of the 24 indicators) have been transformed using the following Eq. 4.1:

Table 4.5 Number of cities (out of 377) having data for two paired indicators. Green colour: Good data coverage. Red colour: Poor data coverage.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1	367	360	333	333	323	343	335	328	328	258	250	235	210	205	205	205	199	198	183	181	169	176	144	144	138	112	103	80	78
2	360	367	333	333	324	336	335	321	321	252	249	234	213	203	201	201	198	195	181	183	168	177	143	145	135	111	103	79	78
3	333	333	335	335	321	332	334	294	294	254	246	208	207	204	200	200	199	195	183	183	169	177	144	146	135	111	104	80	79
4	333	333	335	335	321	332	334	294	294	254	246	208	207	204	200	200	199	195	183	183	169	177	144	146	135	111	104	80	79
5	323	324	321	321	324	323	321	285	285	246	243	205	202	197	200	200	193	191	176	181	163	175	138	143	134	110	101	77	76
6	343	336	332	332	323	344	334	306	306	258	249	213	210	206	205	205	199	199	184	181	169	176	144	144	138	113	103	80	78
7	335	335	334	334	321	334	336	296	296	253	246	208	209	204	201	201	198	196	182	182	168	177	143	145	136	111	103	79	78
8	328	321	294	294	285	306	296	329	329	256	211	198	172	168	167	167	161	164	146	179	131	174	106	106	103	110	65	77	75
9	328	321	294	294	285	306	296	329	329	256	211	198	172	168	167	167	161	164	146	179	131	174	106	106	103	110	65	77	75
10	258	252	254	254	246	258	253	256	256	261	190	148	157	143	145	145	140	135	123	182	110	153	87	87	81	95	54	64	62
11	250	249	246	246	243	249	246	211	211	190	250	166	149	153	178	178	154	146	132	130	124	146	122	118	120	105	98	75	73
12	235	234	208	208	205	213	208	198	198	148	166	238	162	167	171	171	201	157	161	106	171	118	146	146	79	92	102	77	75
13	210	213	207	207	202	210	209	172	172	157	149	162	217	185	150	150	151	178	163	116	149	91	126	128	94	93	86	67	65
14	205	203	204	204	197	206	204	168	168	143	153	167	185	208	154	154	159	197	186	98	157	85	134	138	104	100	99	78	76
15	205	201	200	200	200	205	201	167	167	145	178	171	150	154	206	206	167	148	132	88	137	110	137	115	95	98	100	64	63
16	205	201	200	200	200	205	201	167	167	145	178	171	150	154	206	206	167	148	132	88	137	110	137	115	95	98	100	64	63
17	199	198	199	199	193	199	198	161	161	140	154	201	151	159	167	167	201	150	153	100	170	111	145	141	76	83	102	69	68
18	198	195	195	195	191	199	196	164	164	135	146	157	178	197	148	148	150	199	175	91	147	79	124	128	102	97	92	71	69
19	183	181	183	183	176	184	182	146	146	123	132	161	163	186	132	132	153	175	186	92	151	83	128	134	82	78	99	78	76
20	181	183	183	183	181	181	182	179	179	182	130	106	116	98	88	88	100	91	92	184	90	125	67	80	52	73	51	58	58
21	169	168	169	169	163	169	168	131	131	110	124	171	149	157	137	137	170	147	151	90	171	83	144	139	76	74	99	66	65
22	176	177	177	177	175	176	177	174	174	153	146	118	91	85	110	110	111	79	83	125	83	178	74	76	48	78	60	68	68
23	144	143	144	144	138	144	143	106	106	87	122	146	126	134	137	137	145	124	128	67	144	74	146	117	76	73	101	66	65
24	144	145	146	146	143	144	145	106	106	87	118	146	128	138	115	115	141	128	134	80	139	76	117	146	63	75	101	71	71
25	138	135	135	135	134	138	136	103	103	81	120	79	94	104	95	95	76	102	82	52	76	48	76	63	138	42	48	17	16
26	112	111	111	111	110	113	111	110	110	95	105	92	93	100	98	98	83	97	78	73	74	78	73	75	42	115	65	80	78
27	103	103	104	104	101	103	103	65	65	54	98	102	86	99	100	100	102	92	99	51	99	60	101	101	48	65	105	66	66
28	80	79	80	80	77	80	79	77	77	64	75	77	67	78	64	64	69	71	78	58	66	68	66	71	17	80	66	82	80
29	78	78	79	79	76	78	78	75	75	62	73	75	65	76	63	63	68	69	76	58	65	68	65	71	16	78	66	80	80

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- DE1028V: Total Resident Population 65-74
- DE1055V: Total Resident Population 75 and over

As should be expected, the two variables are highly correlated (0.96). The resulting variable counts all people aged 65 and over.

The information contained in the indicator “EC3055I Percentage households with less than 60% of the national median annual disposable income” is well represented in the indicator “EC3057I Percentage households with less than half the national average income” (correlation 0.86). EC3055I was therefore excluded in the principal component analysis. As a result, the 29 indicators used in the correlation analysis were reduced to 24 indicators for the principal component analysis. Table 4.6 lists the 24 indicators included in the principal component analysis. To assure that all indicators have zero to infinity range, all indicators measured in percent ranging from zero to hundred (a total of 14 out of the 24 indicators) have been transformed using the following Eq. 4.1:

Table 4.5 shows the number of cities (out of 377) having data for two paired indicators. Green colour is used for indicator pairs with good data coverage. Red colour is used for indicator pair with poor data coverage. The diagonal in The off-diagonal elements in **Error! Not a valid bookmark self-reference.** show how much data can be found on each pair of indicators. Most of the data can be found for indicator pair 1 and 2 with 360 cities having corresponding data. The least data can be found for indicator pair 25 and 29 ("SA1018I: Proportion of dwellings lacking basic amenities" and "EC3055I: Percent households with less than 60% of the national median annual disposable income") with only 16 of 377 cities having collected both these indicators.

A large amount of data are missing, and this should be kept in mind when interpreting and using the results from the correlation and PCA analysis, as this significantly weakens the rigour of the results. However, it is still believed that the results can be of practical use in studying underlying structures in the societies the data covers.

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As should be expected, the two variables are highly correlated (0.96). The resulting variable counts all people aged 65 and over.

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Table 4.5 gives more details on the number of cities (out of the 377) that have collected data on the various indicators. The indicators with most data are indicator nos. 1 and 2 with 367 out of the 377 cities having collected data, whereas only 80 out of the 377 cities have data on indicator no. 29.

$$i_{tr} = \frac{i/_{100}}{1 - i/_{100}} \quad (4.1)$$

Table 4.7 shows the correlation matrix between the 24 transformed indicators. Green colour is used to indicate high positive correlation. Red colour is used to indicate high negative correlation. Yellow colour indicates relatively low correlation. The eigenvectors with corresponding eigenvalues resulting from the principal component analysis are shown in Table 4.8. Eigenvector components with high positive value are marked in green. Eigenvector components with high negative value are marked in red. The eigenvectors are sorted by decreasing eigenvalue, showing the eigenvector representing the largest variation (16.2%) in the data set in the first row and the eigenvector representing the least variation (0.01%) in row number 24. The dimensions of the data set can now be reduced by omitting the principal components representing the least variation in the data set. The third column counter from the right in Table 4.8 shows cumulative explanation of variability as more eigenvectors are included in the new data set. For example, including 10 out of the 24 eigenvectors, i.e. all eigenvectors with eigenvalues larger than 0.99, gives a data set containing 81.3 % of the variation in the original data set.

Table 4.6 The 24 indicators included in the principal component analysis. A total of 14 out of the 24 indicators have been transformed.

No	Indicator	Trans-formed
1	DE1003I: Proportion of females to males in total population	
2	SA2016I: Mortality rate for <65 per year	
3	DE1040I: Proportion of total population aged 0-4	Y
4	SA2029I: Crude death rate per 1000 residents	
5	DE1028V + DE1055V: Total Resident Population 65 and over	
6	EN5101I: Population density: total resident pop. per square km	
7	SA3001I: Total Number of recorded crimes per 1000 population	
8	DE3003I: Total number of households	
9	EC1020I: Unemployment rate	Y
10	TE2028I: Prop. of working age population qualified at level 3 or 4 ISCED	Y
11	DE2005I: Proportion of Residents who are not EU Nationals and citizens of a country with high HDI	Y
12	DE2006I: Proportion of Residents who are not EU Nationals and citizens of a country with a medium or low HDI	Y
13	DE3004I: Average size of households	
14	TE2025I: Prop. of working age population qualified at level 1 or 2 ISCED	Y

15	TE2031I: Prop. of working age population qualified at level 5 or 6 ISCED	Y
16	EN5012I: Proportion of the area in green space	Y
17	DE3005I: Prop. of households that are lone-parent households	Y
18	EN5001I: Green space (in m2) to which the public has access per capita	
19	DE3008I: Prop. households that are lone-pensioner households	Y
20	SA1012I: Proportion of households living in social housing	Y
21	SA1018I: Proportion of dwellings lacking basic amenities	Y
22	EC3039I: Median disposable annual household income (for city or NUTS 3 region)	
23	EC3060I: Proportion of households reliant upon social security	Y
24	EC3057I: Percent of households with less than half net.over.income	Y

Table 4.7 Correlation matrix between the 24 transformed indicators. Green colour is used to indicate high positive correlation. Red colour is used to indicate high negative correlation. Yellow colour indicates relatively low correlation.

		1	2	3	4	5	6	7
1	DE1003I: Proportion of females to males in total population	1	0.45	-0.4	0.3	0.07	0.09	-0.23
2	SA2016I: Mortality rate for <65 per year	0.45	1	-0.3	0.54	-0.01	-0.09	-0.08
3	DE1040I: Proportion of total population aged 0-4	-0.4	-0.3	1	-0.45	-0.03	-0.12	0.14
4	SA2029I: Crude death rate per 1000 residents	0.3	0.54	-0.45	1	0.09	0.07	0.15
5	DE1028V + DE1055V: Total Resident Population 65 and over	0.07	-0.01	-0.03	0.09	1	0.35	0.12
6	EN5101I: Population density: total resident pop. per square km	0.09	-0.09	-0.12	0.07	0.35	1	-0.05
7	SA3001I: Total Number of recorded crimes per 1000 population	-0.23	-0.08	0.14	0.15	0.12	-0.05	1
8	DE3003I: Total number of households	-0.05	-0.03	0.01	-0.03	0.94	0.3	0.21
9	EC1020I: Unemployment rate	0.25	0.1	-0.12	-0.06	-0.02	0.04	0.1
10	TE2028I: Prop. of working age population qualified at level 3 or 4 ISCED	0.36	0.5	-0.23	0.24	-0.1	-0.21	0.03
11	DE2005I: Proportion of Residents who are not EU Nationals and citizens of a country with high HDI	-0.17	-0.07	-0.16	0.11	0.22	0.23	0.22
12	DE2006I: Proportion of Residents who are not EU Nationals and citizens of a country with a medium or low HDI	0.04	0.09	0.07	0.09	0.33	0.48	0.18
13	DE3004I: Average size of households	-0.03	-0.31	0.21	-0.39	-0.08	0.06	-0.62
14	TE2025I: Prop. of working age population qualified at level 1 or 2 ISCED	-0.07	-0.16	-0.02	-0.15	0.04	0.22	-0.37
15	TE2031I: Prop. of working age population qualified at level 5 or 6 ISCED	0.1	-0.25	0.13	-0.37	0.04	-0.02	0.03
16	EN5012I: Proportion of the area in green space	-0.18	-0.25	-0.04	-0.12	-0.2	-0.29	0.15
17	DE3005I: Prop. of households that are lone-parent households	0.02	0.14	0.56	-0.16	0.1	-0.12	0.23
18	EN5001I: Green space (in m2) to which the public has access per capita	0	-0.1	-0.01	-0.1	-0.06	-0.16	-0.09
19	DE3008I: Prop. households that are lone-pensioner households	0.33	0.33	-0.33	0.51	0.3	-0.13	0.16
20	SA1012I: Proportion of households living in social housing	-0.32	-0.18	0.48	-0.12	-0.01	0.21	0.19
21	SA1018I: Proportion of dwellings lacking basic amenities	0.45	0.69	-0.21	0.35	-0.09	-0.17	-0.13
22	EC3039I: Median disposable annual household income (for city or NUTS 3 region)	-0.54	-0.42	0.35	0.05	0.07	0.02	0.42
23	EC3060I: Proportion of households reliant upon social security	-0.15	0.08	0.37	-0.06	-0.23	-0.19	-0.06
24	EC3057I: Percent. households with less than half nat.aver.income	-0.15	-0.1	0.12	-0.07	-0.07	-0.01	-0.11

		8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	DE1003I: Proportion of females to males in total population	-0.05	0.25	0.36	-0.17	0.04	-0.03	-0.07	0.1	-0.18	0.02	0	0.33	-0.32	0.45	-0.54	-0.15	-0.15
2	SA2016I: Mortality rate for <65 per year	-0.03	0.1	0.5	-0.07	0.09	-0.31	-0.16	-0.25	-0.25	0.14	-0.1	0.33	-0.18	0.69	-0.42	0.08	-0.1
3	DE1040I: Proportion of total population aged 0-4	0.01	-0.12	-0.23	-0.16	0.07	0.21	-0.02	0.13	-0.04	0.56	-0.01	-0.33	0.48	-0.21	0.35	0.37	0.12
4	SA2029I: Crude death rate per 1000 residents	-0.03	-0.06	0.24	0.11	0.09	-0.39	-0.15	-0.37	-0.12	-0.16	-0.1	0.51	-0.12	0.35	0.05	-0.06	-0.07
5	DE1028V + DE1055V: Total Resident Population 65 and over	0.94	-0.02	-0.1	0.22	0.33	-0.08	0.04	0.04	-0.2	0.1	-0.06	0.3	-0.01	-0.09	0.07	-0.23	-0.07
6	EN5101I: Population density: total resident pop. per square km	0.3	0.04	-0.21	0.23	0.48	0.06	0.22	-0.02	-0.29	-0.12	-0.16	-0.13	0.21	-0.17	0.02	-0.19	-0.01
7	SA3001I: Total Number of recorded crimes per 1000 population	0.21	0.1	0.03	0.22	0.18	-0.62	-0.37	0.03	0.15	0.23	-0.09	0.16	0.19	-0.13	0.42	-0.06	-0.11
8	DE3003I: Total number of households	1	-0.02	-0.13	0.34	0.31	-0.14	0	0.15	-0.23	0.07	-0.08	0.24	0.03	0.03	0.11	-0.19	-0.07
9	EC1020I: Unemployment rate	-0.02	1	0.27	-0.29	-0.01	-0.04	0.22	-0.06	0.08	0.44	0.01	0.09	-0.13	-0.08	-0.19	0.2	-0.19
10	TE2028I: Prop. of working age population qualified at level 3 or 4 ISCED	-0.13	0.27	1	-0.13	0.06	-0.29	-0.36	-0.09	0.25	-0.09	0.05	0.37	-0.4	0.32	-0.39	-0.3	-0.22
11	DE2005I: Proportion of Residents who are not EU Nationals and citizens of a country with high HDI	0.34	-0.29	-0.13	1	0.52	-0.27	0.1	-0.09	-0.1	-0.16	-0.13	0.05	-0.21	-0.09	0.27	-0.31	0.07
12	DE2006I: Proportion of Residents who are not EU Nationals and citizens of a country with a medium or low HDI	0.31	-0.01	0.06	0.52	1	-0.16	0.07	-0.23	-0.22	0.25	-0.17	0.07	-0.17	0.11	0.31	-0.18	-0.02
13	DE3004I: Average size of households	-0.14	-0.04	-0.29	-0.27	-0.16	1	0.51	-0.25	-0.01	-0.03	0.07	-0.48	-0.04	-0.1	-0.29	0.37	0.38
14	TE2025I: Prop. of working age population qualified at level 1 or 2 ISCED	0	0.22	-0.36	0.1	0.07	0.51	1	-0.28	-0.25	-0.01	-0.26	-0.36	0.13	-0.29	0.01	0.49	0.04
15	TE2031I: Prop. of working age population qualified at level 5 or 6 ISCED	0.15	-0.06	-0.09	-0.09	-0.23	-0.25	-0.28	1	0	-0.25	0.17	-0.18	0.09	0.17	0.18	0.02	0.18
16	EN5012I: Proportion of the area in green space	-0.23	0.08	0.25	-0.1	-0.22	-0.01	-0.25	0	1	-0.05	0.28	0.09	-0.19	-0.21	-0.25	-0.04	-0.18
17	DE3005I: Prop. of households that are lone-parent households	0.07	0.44	-0.09	-0.16	0.25	-0.03	-0.01	-0.25	-0.05	1	-0.08	0.05	0.25	0.01	0.31	0.25	0.11
18	EN5001I: Green space (in m2) to which the public has access per capita	-0.08	0.01	0.05	-0.13	-0.17	0.07	-0.26	0.17	0.28	-0.08	1	-0.04	0.02	-0.06	-0.24	0.38	-0.37
19	DE3008I: Prop. households that are lone-pensioner households	0.24	0.09	0.37	0.05	0.07	-0.48	-0.36	-0.18	0.09	0.05	-0.04	1	-0.21	0.31	-0.02	-0.39	-0.13
20	SA1012I: Proportion of households living in social housing	0.03	-0.13	-0.4	-0.21	-0.17	-0.04	0.13	0.09	-0.19	0.25	0.02	-0.21	1	-0.26	0.52	0.53	0.17
21	SA1018I: Proportion of dwellings lacking basic amenities	0.03	-0.08	0.32	-0.09	0.11	-0.1	-0.29	0.17	-0.21	0.01	-0.06	0.31	-0.26	1	-0.58	-0.06	0.06
22	EC3039I: Median disposable annual household income (for city or NUTS 3 region)	0.11	-0.19	-0.39	0.27	0.31	-0.29	0.01	0.18	-0.25	0.31	-0.24	-0.02	0.52	-0.58	1	-0.12	0.46
23	EC3060I: Proportion of households reliant upon social security	-0.19	0.2	-0.3	-0.31	-0.18	0.37	0.49	0.02	-0.04	0.25	0.38	-0.39	0.53	-0.06	-0.12	1	0.3
24	EC3057I: Percent. households with less than half nat.aver.income	-0.07	-0.19	-0.22	0.07	-0.02	0.38	0.04	0.18	-0.18	0.11	-0.37	-0.13	0.17	0.06	0.46	0.3	1

Table 4.9, which shows correlation between the principal components (PC1 to PC24) and each of the 24 original indicators, can be used to find which indicators dominate each of the

principal components. It can be seen that on average, decreasing correlation between the indicators and the principal components is found for increasing principal component number.

Table 4.8 Eigenvectors and eigenvalues resulting from principal component analysis sorted by decreasing eigenvalue. Eigenvector components with high positive value marked in green. Eigenvector components with high negative value marked in red.

	Eigen vector no	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	Explanation of variability (%)	16.2	13.4	9.95	8.73	7.45	7.05	5.32	4.65	4.57	3.93	3.03	2.87	2.16	1.95	1.69	1.28	1.19	1.09	0.97	0.81	0.67	0.56	0.35	0.01
	Cumulative explanation of variability (%)	16.2	29.7	39.6	48.4	55.8	62.9	68.2	72.8	77.4	81.3	84.4	87.2	89.4	91.3	93	94.3	95.5	96.6	97.6	98.4	99	99.6	99.9	100
	Eigen value	4.07	3.39	2.5	2.19	1.87	1.77	1.33	1.17	1.15	0.99	0.76	0.72	0.54	0.49	0.42	0.32	0.3	0.27	0.24	0.2	0.17	0.14	0.09	0
	Indicator code	EIGEN VECTOR COMPONENTS																							
1	DE1003I	-0.31	0.09	0.15	-0.14	-0.07	0.08	0.12	0.25	-0.23	0.01	0.4	0	0.1	0.12	-0.61	0.25	-0.02	0.05	-0.03	-0.09	-0.11	0.14	-0.01	0.22
2	SA2016I	-0.34	0.06	0.04	-0.31	0.24	0.1	0.01	-0.06	0.1	-0.01	-0.21	0.22	-0.05	-0.06	0.17	0.32	-0.06	-0.15	-0.04	0.01	0.04	-0.38	-0.44	0.31
3	DE1040I	0.34	0.01	-0.12	-0.29	-0.02	0.02	0.29	-0.21	0.13	0.01	0.21	0.03	0.12	-0.08	-0.11	-0.23	0.03	0.05	0.43	-0.07	0.05	-0.33	0.22	0.4
4	SA2029I	-0.31	-0.11	-0.08	-0.1	0.28	-0.04	-0.42	0.02	0.1	0.02	0.08	0.14	-0.13	0.11	-0.15	-0.3	-0.15	-0.24	0.51	0.06	0.21	0.21	0.02	-0.09
5	DE1028V	-0.05	-0.4	0.17	-0.14	-0.4	0.2	-0.14	-0.18	0.02	0.02	-0.01	0.1	-0.07	0	-0.07	0.02	0	0.29	0.04	0.65	-0.04	-0.02	-0.04	0.04
6	EN5101I	0.06	-0.25	0.35	0.01	0.03	-0.15	0.02	0.42	0.1	0.04	0.34	0.27	-0.13	0.19	0.29	0.1	0.1	0.25	0.13	-0.18	0.08	-0.29	0.04	-0.21
7	SA3001I	0.02	-0.25	-0.42	-0.09	-0.01	-0.14	0.06	0.19	0.14	-0.09	-0.22	-0.06	-0.23	0.37	-0.3	0.03	-0.06	-0.14	-0.11	0.04	-0.36	-0.35	0.12	-0.16
8	DE3003I	-0.02	-0.37	0.14	-0.14	-0.4	0.28	-0.05	-0.17	0.07	-0.02	-0.21	0.15	-0.08	0.01	-0.01	0.02	0.01	-0.21	0.01	-0.63	-0.04	0.18	0.05	0.03
9	EC1020I	-0.05	0.08	0.01	-0.27	-0.25	-0.33	-0.02	0.33	-0.45	0.02	-0.37	0	-0.15	0.04	0.11	-0.1	0.09	-0.03	-0.01	0.06	0.33	0.01	0.25	0.27
10	TE2028I	-0.31	0.13	-0.16	-0.01	-0.15	-0.19	0.17	-0.01	0.1	0.08	-0.05	0.42	-0.08	-0.61	-0.19	-0.07	0.1	0.11	0	-0.04	-0.06	-0.08	0.13	-0.33
11	DE2005I	-0.04	-0.34	0.09	0.2	0.18	-0.12	0.15	0.02	0.21	0.21	-0.31	-0.08	0.43	0.02	-0.28	0.2	0.31	-0.03	0.03	0.04	0.41	-0.02	0.06	-0.01
12	DE2006I	-0.05	-0.33	0.16	-0.12	0.13	-0.28	0.32	0.06	0.15	0.29	0.16	0.01	0.02	-0.11	0.12	-0.31	-0.34	-0.24	-0.34	0.11	-0.12	0.22	-0.03	0.18
13	DE3004I	0.19	0.25	0.38	0.01	-0.04	-0.03	0.01	-0.3	0.02	0.03	0.03	0.11	-0.29	0.17	-0.35	-0.15	-0.12	-0.2	-0.28	0.03	0.38	-0.26	-0.04	-0.2
14	TE2025I	0.16	0.03	0.44	-0.03	0.07	-0.15	-0.24	0.08	-0.17	-0.01	-0.32	-0.05	0.34	-0.2	-0.14	-0.03	-0.37	0.01	0.21	-0.05	-0.37	-0.21	0.02	-0.11
15	TE2031I	0.08	0	-0.12	0.12	-0.16	0.5	0.3	0.43	-0.16	0	-0.05	0.08	0.19	-0.03	0	-0.26	-0.16	-0.24	0.11	0.11	0.17	-0.11	-0.28	-0.2
16	EN5012I	0.01	0.15	-0.27	0.22	-0.31	-0.25	-0.07	-0.12	0.06	0.21	0	0.4	0.31	0.35	0.05	0.12	-0.42	0.15	0.02	-0.06	0.09	0.04	-0.09	0.11
17	DE3005I	0.11	-0.04	-0.1	-0.52	-0.07	-0.23	0.2	-0.2	-0.2	0.13	0.1	-0.2	0.09	0.06	0.07	0.25	0	-0.05	0.19	-0.01	0.08	0.15	-0.28	-0.5
18	EN5001I	0.03	0.17	-0.04	-0.01	-0.21	0.14	-0.2	0.21	0.3	0.64	0.03	-0.39	-0.23	-0.17	0	0.21	-0.15	-0.03	0.09	-0.03	0.06	-0.1	0.08	0.04
19	DE3008I	-0.27	-0.18	-0.18	-0.05	-0.09	0.01	-0.35	-0.13	-0.25	0.11	0.29	-0.21	0.34	-0.05	0.08	-0.27	0.09	-0.02	-0.3	-0.14	0.1	-0.43	0.03	-0.07
20	SA1012I	0.29	-0.01	-0.13	-0.3	0.11	0.15	-0.25	0.17	0.13	-0.22	0.14	0.22	0.21	-0.18	0.03	0.33	-0.18	-0.2	-0.28	0.12	0.19	0.09	0.37	-0.07
21	SA1018I	-0.32	0.11	0.06	-0.23	0.22	0.33	0.24	-0.08	0.06	0.05	-0.21	-0.1	0.06	0.23	0.1	-0.11	-0.29	0.44	-0.08	-0.08	0.09	0.02	0.38	-0.18
22	EC3039I	0.27	-0.3	-0.24	0.03	0.26	0.02	-0.1	0.04	-0.23	0.03	-0.05	0	-0.26	-0.24	-0.23	-0.01	-0.25	0.46	-0.1	-0.21	0.22	0.04	-0.28	0.09
23	EC3060I	0.21	0.21	0	-0.36	0.05	0.06	-0.22	0.19	0.23	0.22	-0.13	0.19	0.17	0.16	-0.12	-0.34	0.38	0.2	-0.21	-0.04	-0.16	0.17	-0.25	0
24	EC3057I	0.13	-0.06	-0.04	0.09	0.29	0.22	0.02	-0.17	-0.47	0.52	-0.01	0.35	-0.09	0.09	0.05	0.12	0.17	-0.16	0.02	0.07	-0.22	-0.01	0.23	-0.02

Table 4.9 Correlation between principal components (PC1 to PC24) and each of the original indicators. Green: Strong positive correlation. Yellow: Low correlation. Red: Strong negative correlation.

	INDICAOTRS	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13	PC14	PC15	PC16	PC17	PC18
1	DE1003I: Proportion of females to males in total population	0.62	-0.17	0.24	0.21	0.10	0.10	-0.14	0.27	0.25	0.01	0.35	0.00	0.08	-0.08	0.40	-0.14	0.01	-0.02
2	SA2016I: Mortality rate for <65 per year	0.69	-0.12	0.06	0.46	-0.33	0.14	-0.01	-0.06	-0.11	-0.01	-0.18	0.19	-0.04	0.04	-0.11	-0.18	0.03	0.08
3	DE1040I: Proportion of total population aged 0-4	-0.68	-0.03	-0.19	0.43	0.02	0.03	-0.34	-0.22	-0.14	0.01	0.18	0.03	0.09	0.06	0.07	0.13	-0.02	-0.03
4	SA2029I: Crude death rate per 1000 residents	0.62	0.21	-0.12	0.14	-0.39	-0.05	0.48	0.03	-0.10	0.02	0.07	0.12	-0.10	-0.08	0.10	0.17	0.08	0.13
5	DE1028V + DE1055V: Total Resident Population 65 and over	0.10	0.73	0.26	0.21	0.55	0.27	0.16	-0.19	-0.02	0.02	-0.01	0.09	-0.05	0.00	0.05	-0.01	0.00	-0.15
6	EN5101I: Population density: total resident pop. per square km	-0.11	0.46	0.56	-0.02	-0.05	-0.20	-0.02	0.46	-0.11	0.04	0.29	0.23	-0.10	-0.13	-0.19	-0.06	-0.05	-0.13
7	SA3001I: Total Number of recorded crimes per 1000 population	-0.04	0.46	-0.66	0.13	0.01	-0.19	-0.07	0.20	-0.15	-0.09	-0.19	-0.05	-0.17	-0.26	0.20	-0.01	0.03	0.07
8	DE3003I: Total number of households	0.04	0.68	0.22	0.21	0.55	0.37	0.06	-0.19	-0.07	-0.02	-0.18	0.12	-0.06	-0.01	0.01	-0.01	-0.01	0.11
9	EC1020I: Unemployment rate	0.11	-0.15	0.02	0.39	0.34	-0.43	0.02	0.36	0.48	0.02	-0.32	0.00	-0.11	-0.03	-0.07	0.06	-0.05	0.02
10	TE2028I: Prop. of working age population qualified at level 3 or 4 ISCED	0.62	-0.24	-0.25	0.01	0.21	-0.25	-0.20	-0.01	-0.11	0.08	-0.04	0.36	-0.06	0.43	0.12	0.04	-0.05	-0.06
11	DE2005I: Proportion of Residents who are not EU Nationals and citizens of a country with high HDI	0.08	0.63	0.14	-0.30	-0.24	-0.16	-0.17	0.02	-0.23	0.21	-0.27	-0.07	0.32	-0.01	0.19	-0.11	-0.17	0.02
12	DE2006I: Proportion of Residents who are not EU Nationals and citizens of a country with a medium or low HDI	0.09	0.61	0.25	0.18	-0.17	-0.37	-0.37	0.07	-0.16	0.28	0.14	0.01	0.01	0.08	-0.08	0.17	0.18	0.13
13	DE3004I: Average size of households	-0.38	-0.46	0.60	-0.02	0.05	-0.05	-0.02	-0.33	-0.02	0.03	0.03	0.09	-0.21	-0.12	0.23	0.08	0.07	0.11
14	TE2025I: Prop. of working age population qualified at level 1 or 2 ISCED	-0.33	-0.05	0.69	0.05	-0.09	-0.19	0.28	0.08	0.19	-0.01	-0.28	-0.04	0.25	0.14	0.09	0.01	0.20	0.00
15	TE2031I: Prop. of working age population qualified at level 5 or 6 ISCED	-0.16	-0.01	-0.19	-0.17	0.22	0.66	-0.35	0.47	0.17	0.00	-0.04	0.07	0.14	0.02	0.00	0.15	0.09	0.13
16	EN5012I: Proportion of the area in green space	-0.02	-0.27	-0.43	-0.32	0.42	-0.33	0.08	-0.13	-0.06	0.21	0.00	0.34	0.23	-0.25	-0.03	-0.07	0.23	-0.08
17	DE3005I: Prop. of households that are lone-parent households	-0.21	0.06	-0.16	0.76	0.09	-0.30	-0.23	-0.22	0.21	0.13	0.08	-0.17	0.07	-0.04	-0.05	-0.14	0.00	0.03
18	EN5001I: Green space (in m2) to which the public has access per capita	-0.06	-0.32	-0.06	0.01	0.28	0.18	0.23	0.23	-0.32	0.63	0.02	-0.33	-0.17	0.12	0.00	-0.12	0.08	0.02
19	DE3008I: Prop. households that are lone-pensioner households	0.55	0.33	-0.28	0.08	0.12	0.01	0.40	-0.14	0.26	0.11	0.25	-0.17	0.25	0.03	-0.05	0.15	-0.05	0.01
20	SA1012I: Proportion of households living in social housing	-0.59	0.02	-0.21	0.44	-0.15	0.21	0.29	0.18	-0.14	-0.22	0.12	0.19	0.15	0.12	-0.02	-0.19	0.10	0.10
21	SA1018I: Proportion of dwellings lacking basic amenities	0.64	-0.20	0.10	0.33	-0.30	0.44	-0.27	-0.09	-0.06	0.05	-0.18	-0.09	0.05	-0.16	-0.06	0.06	0.16	-0.23
22	EC3039I: Median disposable annual household income (for city or NUTS 3 region)	-0.54	0.55	-0.37	-0.04	-0.36	0.03	0.11	0.04	0.24	0.03	-0.05	0.00	-0.19	0.17	0.15	0.00	0.14	-0.24
23	EC3060I: Proportion of households reliant upon social security	-0.41	-0.39	0.01	0.53	-0.07	0.08	0.26	0.20	-0.25	0.22	-0.11	0.16	0.13	-0.11	0.08	0.19	-0.21	-0.10
24	EC3057I: Percent. households with less than half nat.aver.income	-0.26	0.11	-0.07	-0.14	-0.39	0.29	-0.02	-0.18	0.50	0.52	0.00	0.29	-0.07	-0.06	-0.03	-0.07	-0.09	0.08

	INDICAOTRS	PC19	PC20	PC21	PC22	PC23	PC24
1	DE1003I: Proportion of females to males in total population	-0.02	0.04	-0.05	-0.05	0.00	0.01
2	SA2016I: Mortality rate for <65 per year	-0.02	-0.01	0.02	0.14	0.13	0.01
3	DE1040I: Proportion of total population aged 0-4	0.21	0.03	0.02	0.12	-0.06	0.02
4	SA2029I: Crude death rate per 1000 residents	0.25	-0.03	0.09	-0.08	-0.01	0.00
5	DE1028V + DE1055V: Total Resident Population 65 and over	0.02	-0.29	-0.02	0.01	0.01	0.00
6	EN5101I: Population density: total resident pop. per square km	0.06	0.08	0.03	0.11	-0.01	-0.01
7	SA3001I: Total Number of recorded crimes per 1000 population	-0.05	-0.02	-0.15	0.13	-0.04	-0.01
8	DE3003I: Total number of households	0.00	0.28	-0.01	-0.07	-0.02	0.00
9	EC1020I: Unemployment rate	-0.01	-0.03	0.14	0.00	-0.07	0.01
10	TE2028I: Prop. of working age population qualified at level 3 or 4 ISCED	0.00	0.02	-0.02	0.03	-0.04	-0.01
11	DE2005I: Proportion of Residents who are not EU Nationals and citizens of a country with high HDI	0.02	-0.02	0.17	0.01	-0.02	0.00
12	DE2006I: Proportion of Residents who are not EU Nationals and citizens of a country with a medium or low HDI	-0.17	-0.05	-0.05	-0.08	0.01	0.01
13	DE3004I: Average size of households	-0.14	-0.01	0.15	0.10	0.01	-0.01
14	TE2025I: Prop. of working age population qualified at level 1 or 2 ISCED	0.10	0.02	-0.15	0.08	-0.01	0.00
15	TE2031I: Prop. of working age population qualified at level 5 or 6 ISCED	0.05	-0.05	0.07	0.04	0.08	-0.01
16	EN5012I: Proportion of the area in green space	0.01	0.03	0.04	-0.02	0.03	0.00
17	DE3005I: Prop. of households that are lone-parent households	0.09	0.00	0.03	-0.06	0.08	-0.02
18	EN5001I: Green space (in m2) to which the public has access per capita	0.04	0.01	0.02	0.04	-0.02	0.00
19	DE3008I: Prop. households that are lone-pensioner households	-0.15	0.06	0.04	0.16	-0.01	0.00
20	SA1012I: Proportion of households living in social housing	-0.14	-0.05	0.08	-0.03	-0.11	0.00
21	SA1018I: Proportion of dwellings lacking basic amenities	-0.04	0.03	0.04	-0.01	-0.11	-0.01
22	EC3039I: Median disposable annual household income (for city or NUTS 3 region)	-0.05	0.09	0.09	-0.01	0.08	0.00
23	EC3060I: Proportion of households reliant upon social security	-0.10	0.02	-0.06	-0.06	0.07	0.00
24	EC3057I: Percent. households with less than half nat.aver.income	0.01	-0.03	-0.09	0.00	-0.07	0.00

The strongly correlated indicators for principal component number one (e.g, proportion of households living in social housing, proportion of households lacking basic amenities; high mortality rate of less than 65 years, can be thought of as characteristics describing poverty) Principal component no 1 could therefore *subjectively* be termed *Proportion of poor people*.

The results of a similar analysis for the first eight principal components, representing close to 75% of the variation in the data, can be found in Table 4.10. Along with the subjective descriptor is listed the indicator most strongly correlated (either positive or negative) with the principal component and the corresponding correlation value.

Table 4.10 Subjective labelling of the first eight principal components representing close to 75% of the variation in the data

No	***Subjective descriptor for principal component***	***Strongest correlated indicator***	***Strongest correlation value***
1	Proportion of poor people	SA2016I: Mortality rate for <65 per year	+0.69
2	Proportion of old people	DE1028V + DE1055V: Total Resident Population 65 and over	+0.73
3	Proportion of uneducated people	TE2025I: Prop. of working age population qualified at level 1 or 2 ISCED	+0.69
4	Proportion of households that are lone-parent households	DE3005I: Prop. of households that are lone-parent households	+0.76

5	Size of sub-city district	DE3003I: Total number of households	+0.55
6	Proportion of highly educated people	TE2031I: Prop. of working age population qualified at level 5 or 6 ISCED	+0.66
7	Crude death rate per 1000 residents	SA2029I: Crude death rate per 1000 residents	+0.48
8	Population density	EN5101I: Population density: total resident pop. per square km	+0.46

4.3.2 Sub-city level analysis

The spatial resolution of interest for determining the need and capacity for setting up emergency shelters and health facilities in a post earthquake situation is normally sub-city level. Although not all data of interest (see Table 4.4) was available in the Urban Audit for 2003-2006, it was decided to analyze the available sub-city level data in order to be able to make comparisons of correlation and principal components to the city level data. A two-step procedure was followed for the sub-city level analysis:

1. The first step was to make a correlation analysis at sub-city level for the same 24 indicators that were included in the principal component analysis at city-level.
2. The second step was to exclude indicators that either were highly correlated to other indicators, or indicators with too little data and then perform a principal component analysis.

Details for each of the two steps can be found below.

A total of 24 indicators were included in the correlation analysis.

Table 4.11 shows the number of sub-city districts (out of 2466) having data for two paired indicators. Green colour is used for indicator pairs with good data coverage. Red colour is used for indicator pairs with poor data coverage. The diagonal in

Table 4.11 gives more details on the number of districts (out of the 2466) that have collected data on the various indicators. The indicator with most data is no. 1 with 2188 out of the 2466 districts having collected data. Indicator no. 2 *DE1028V + DE1055V: Total Resident Population 65 and over* has no data at sub-city district level. Indicator no. 12, *EC3057I: Percent. households with less than half nat. aver. income* is the indicator with the least data (216 out of the 2466 districts).

The off-diagonal elements in

Table 4.11 show how much data can be found on each pair of indicators. The most data can be found for indicator pair 1 and 3 with 2128 districts having corresponding data. Several data pairs have no data at all. This is the case for the six combinations of indicators 12 and 13 with indicators 22, 23 and 24.

Table 4.11 No of sub-city districts (out of 2466) having data for two paired indicators. Green colour: Indicator pair with good data coverage. Red colour: Indicator pair with poor data coverage.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	DE1003I: Proportion of females to males in total population	2188																							
2	DE1028V + DE1055V: Total Resident Population 65 and over	0	0																						
3	DE1040I: Proportion of total population aged 0-4	2128	0	2128																					
4	DE2005I: Proportion of Residents who are not EU Nationals and citizens of a country with high HDI	1921	0	1915	1981																				
5	DE2006I: Proportion of Residents who are not EU Nationals and citizens of a country with a medium or low HDI	1921	0	1915	1981	1981																			
6	DE3003I: Total number of households	1594	0	1573	1518	1518	1792																		
7	DE3004I: Average size of households	1540	0	1532	1494	1494	1737	1737																	
8	DE3005I: Prop. of households that are lone-parent households	1546	0	1525	1494	1494	1743	1712	1743																
9	DE3008I: Prop. households that are lone-pensioner households	1380	0	1359	1361	1361	1459	1428	1458	1459															
10	EC1020I: Unemployment rate	1274	0	1248	1192	1192	1201	1161	1177	1048	1334														
11	EC3039I: Median disposable annual household income (for city or NUTS 3 region)	340	0	326	282	282	404	388	393	275	124	459													
12	EC3057I: Percent. households with less than half nat.aver.income	215	0	210	200	200	215	215	215	215	8	216	216												
13	EC3060I: Proportion of households reliant upon social security	589	0	584	559	559	589	584	589	491	381	275	215	589											
14	EN5001I: Green space (in m2) to which the public has access per capita	342	0	336	269	269	221	221	211	199	65	245	199	199	377										
15	EN5012I: Proportion of the area in green space	664	0	638	569	569	408	397	397	351	257	304	210	360	344	697									
16	EN5101I: Population density: total resident pop. per square km	1491	0	1485	1371	1371	1278	1261	1267	1039	898	432	204	576	344	670	1636								
17	SA1012I: Proportion of households living in social housing	1179	0	1158	1150	1150	1254	1236	1254	1108	862	261	201	555	195	353	1051	1254							
18	SA1018I: Proportion of dwellings lacking basic amenities	1009	0	987	972	972	996	982	996	996	658	213	201	201	232	241	762	758	1064						
19	SA2016I: Mortality rate for <65 per year	1041	0	1004	856	856	689	684	665	528	559	299	187	549	311	591	829	569	188	1041					
20	SA2029I: Crude death rate per 1000 residents	1042	0	1042	914	914	746	730	711	574	635	278	166	528	288	559	831	607	163	977	1102				
21	SA3001I: Total Number of recorded crimes per 1000 population	584	0	584	488	488	399	387	368	310	268	292	196	368	274	360	521	368	207	549	529	607			
22	TE2025I: Prop. of working age population qualified at level 1 or 2 ISCED	536	0	510	438	438	358	353	331	300	368	8	0	0	99	93	79	80	258	264	244	106	559		
23	TE2028I: Prop. of working age population qualified at level 3 or 4 ISCED	542	0	516	441	441	361	356	331	300	368	8	0	0	135	128	115	80	305	267	247	109	559	612	
24	TE2031I: Prop. of working age population qualified at level 5 or 6 ISCED	543	0	517	442	442	361	356	332	300	368	8	0	0	135	129	116	81	305	267	247	108	559	611	614

No zero data indicator combinations can be included in the principal component analysis. For this reason it was decided to exclude indicators number 12 and 13 (*EC3057I: Percent. households with less than half nat.aver.income* and *EC3060I: Proportion of households reliant upon social security*). Also indicator number two (*DE1028V + DE1055V: Total Resident Population 65 and over*) has no data, and was excluded. This leaves 21 indicators for the principal component analysis.

Table 4.12 The 21 indicators included in the principal component analysis. A total of 12 out of the 21 indicators have been transformed using the equation in Section 0.

No	Indicator description	Trans-formed
1	DE1003I: Proportion of females to males in total population	
2	DE1040I: Proportion of total population aged 0-4	Y
3	DE2005I: Proportion of Residents who are not EU Nationals and citizens of a country with high HDI	Y
4	DE2006I: Proportion of Residents who are not EU Nationals and citizens of a country with a medium or low HDI	Y
5	DE3003I: Total number of households	
6	DE3004I: Average size of households	
7	DE3005I: Prop. of households that are lone-parent households	Y
8	DE3008I: Prop. households that are lone-pensioner households	Y
9	EC1020I: Unemployment rate	Y
10	EC3039I: Median disposable annual household income (for city or NUTS 3 region)	
11	EN5001I: Green space (in m2) to which the public has access per capita	
12	EN5012I: Proportion of the area in green space	Y
13	EN5101I: Population density: total resident pop. per square km	
14	SA1012I: Proportion of households living in social housing	Y
15	SA1018I: Proportion of dwellings lacking basic amenities	Y
16	SA2016I: Mortality rate for <65 per year	
17	SA2029I: Crude death rate per 1000 residents	
18	SA3001I: Total Number of recorded crimes per 1000 population	
19	TE2025I: Prop. of working age population qualified at level 1 or 2 ISCED	Y
20	TE2028I: Prop. of working age population qualified at level 3 or 4 ISCED	Y
21	TE2031I: Prop. of working age population qualified at level 5 or 6 ISCED	Y

Table 4.12 lists the 21 indicators included in the principal component analysis. A total of 12 out of the 21 indicators have been transformed using the equation in Section 0.

Table 4.13 shows the correlation matrix between the 21 transformed indicators. Red colour is used to indicate relatively highly correlated indicators (correlation >0.4 or <-0.4). Green colour is used to indicate independent indicators (-0.1 < correlation < 0.1).

Table 4.13 Correlation matrix between the 21 transformed indicators. Red colour: Abs >0.4. Green colour: Abs<0.1.

	Indicator	1	2	3	4	5	6	7	8	9	10	11	12	13
1	DE1003I: Proportion of females to males in total population	1.00												
2	DE1040I: Proportion of total population aged 0-4	-0.28	1.00											
3	DE2005I: Proportion of Residents who are not EU Nationals and citizens of a country with high HDI	-0.06	-0.17	1.00										
4	DE2006I: Proportion of Residents who are not EU Nationals and citizens of a country with a medium or low HDI	-0.19	-0.02	0.37	1.00									
5	DE3003I: Total number of households	-0.06	0.15	0.14	0.14	1.00								
6	DE3004I: Average size of households	0.02	0.10	-0.27	-0.20	-0.20	1.00							
7	DE3005I: Prop. of households that are lone-parent households	-0.24	0.42	-0.05	0.11	0.21	-0.25	1.00						
8	DE3008I: Prop. households that are lone-pensioner households	0.46	-0.47	0.20	0.21	0.34	-0.31	0.07	1.00					
9	EC1020I: Unemployment rate	-0.10	0.02	-0.14	0.08	-0.12	0.02	0.05	0.10	1.00				
10	EC3039I: Median disposable annual household income (for city or NUTS 3 region)	-0.22	0.52	-0.08	-0.35	-0.49	0.16	-0.21	-0.65	-0.34	1.00			
11	EN5001I: Green space (in m2) to which the public has access per capita	0.12	-0.16	0.02	-0.13	-0.13	0.17	-0.12	0.05	0.02	-0.47	1.00		
12	EN5012I: Proportion of the area in green space	0.04	-0.02	-0.12	-0.13	0.01	0.14	-0.06	0.05	-0.04	-0.12	0.38	1.00	
13	EN5101I: Population density: total resident pop. per square km	0.27	-0.27	0.10	0.16	-0.12	0.23	-0.46	0.11	0.03	0.10	-0.46	-0.21	1.00
14	SA1012I: Proportion of households living in social housing	-0.13	0.34	-0.18	0.05	0.00	-0.09	0.35	-0.22	0.09	0.20	-0.06	-0.08	-0.09
15	SA1018I: Proportion of dwellings lacking basic amenities	-0.16	-0.01	-0.03	0.06	-0.21	0.23	-0.13	-0.05	0.08	-0.49	0.07	-0.04	-0.16
16	SA2016I: Mortality rate for <65 per year	0.02	-0.37	0.12	0.28	0.03	-0.07	0.20	0.61	0.42	-0.70	0.33	0.07	-0.15
17	SA2029I: Crude death rate per 1000 residents	0.17	-0.34	0.03	-0.01	-0.04	-0.13	-0.11	0.40	0.17	-0.18	0.06	0.03	-0.13
18	SA3001I: Total Number of recorded crimes per 1000 population	-0.23	-0.24	0.14	0.13	0.17	-0.29	-0.04	0.11	0.10	-0.10	-0.04	-0.12	0.03
19	TE2025I: Prop. of working age population qualified at level 1 or 2 ISCED	-0.18	0.13	-0.05	0.15	-0.07	0.52	0.19	-0.22	0.26	-0.76	0.07	0.17	-0.31
20	TE2028I: Prop. of working age population qualified at level 3 or 4 ISCED	0.11	-0.25	-0.15	-0.01	-0.43	-0.02	-0.41	0.23	0.22	0.34	0.14	0.46	-0.33
21	TE2031I: Prop. of working age population qualified at level 5 or 6 ISCED	0.25	-0.08	0.11	-0.19	-0.01	-0.38	-0.17	0.09	-0.32	0.71	-0.21	-0.28	0.39

	Indicator	14	15	16	17	18	19	20	21
1	DE1003I: Proportion of females to males in total population								
2	DE1040I: Proportion of total population aged 0-4								
3	DE2005I: Proportion of Residents who are not EU Nationals and citizens of a country with high HDI								
4	DE2006I: Proportion of Residents who are not EU Nationals and citizens of a country with a medium or low HDI								
5	DE3003I: Total number of households								
6	DE3004I: Average size of households								
7	DE3005I: Prop. of households that are lone-parent households								
8	DE3008I: Prop. households that are lone-pensioner households								
9	EC1020I: Unemployment rate								
10	EC3039I: Median disposable annual household income (for city or NUTS 3 region)								
11	EN5001I: Green space (in m2) to which the public has access per capita								
12	EN5012I: Proportion of the area in green space								
13	EN5101I: Population density: total resident pop. per square km								
14	SA1012I: Proportion of households living in social housing	1.00							
15	SA1018I: Proportion of dwellings lacking basic amenities	-0.09	1.00						
16	SA2016I: Mortality rate for <65 per year	-0.41	0.30	1.00					
17	SA2029I: Crude death rate per 1000 residents	-0.30	0.03	0.54	1.00				
18	SA3001I: Total Number of recorded crimes per 1000 population	-0.18	-0.05	0.09	0.10	1.00			
19	TE2025I: Prop. of working age population qualified at level 1 or 2 ISCED	0.24	0.03	0.24	-0.07	-0.07	1.00		
20	TE2028I: Prop. of working age population qualified at level 3 or 4 ISCED	-0.60	-0.06	0.21	0.10	-0.43	-0.28	1.00	
21	TE2031I: Prop. of working age population qualified at level 5 or 6 ISCED	-0.23	0.20	-0.25	0.09	0.42	-0.62	-0.28	1.00

The eigenvectors with corresponding eigenvalues resulting from the principal component analysis are shown in Table 4.14. Eigenvector components with high positive value are shown in green. Eigenvector components with high negative value are shown in red. The eigenvectors are sorted by decreasing eigenvalue, showing the eigenvector representing the largest variation (18.3%) in the data set in the first row and the eigenvector representing the least variation (< 0.1%) in row number 21. The dimensions of the data set can now be reduced by omitting the principal components representing the least variation in the data set. The third column counted from the right in Table 4.14 shows cumulative explanation of variability as more eigenvectors are included in the new data set. For example, including 8 out of the 21 eigenvectors, i.e. all eigenvectors with eigenvalues larger than 1.00, gives a data set containing approximately 75% of the variation in the original data set.

Table 4.14 Eigenvectors and eigenvalues resulting from principal component analysis sorted by decreasing eigenvalue. Eigenvector components with high positive and high negative values are shown in green and red, respectively.

	Eigen vector no	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
	Explanation of variability (%)	18.3	12.2	11.1	8	6.7	6.4	5.7	5.3	4.4	3.8	3.3	3	2.7	2.1	1.8	1.5	1.3	1.2	0.6	0.4	0
	Cumulative explanation of variability (%)	18.3	30.5	41.6	49.7	56.4	62.8	68.5	73.8	78.2	82	85.2	88.2	91	93.1	94.9	96.5	97.8	98.9	99.6	100	100
	Eigen value	4.02	2.68	2.45	1.77	1.48	1.41	1.24	1.16	0.97	0.84	0.72	0.66	0.6	0.47	0.39	0.34	0.29	0.26	0.14	0.09	0.01
	Indicator code																					
1	DE1003I: Proportion of females to males in total population	-0.16	-0.03	-0.32	0.15	-0.02	0.43	-0.23	0.1	-0.1	0.14	0.19	-0.37	0.18	-0.21	0.47	-0.02	0.12	-0.09	0.08	-0.12	0.25
2	DE1040I: Proportion of total population aged 0-4	0.37	0.05	0.18	0.1	-0.03	-0.01	-0.06	-0.04	0.34	-0.16	0.3	-0.21	0.2	-0.4	-0.11	0.22	-0.41	0.04	0.31	0.08	-0.03
3	DE2005I: Proportion of Residents who are not EU Nationals and citizens of a country with high HDI	-0.1	-0.21	0.04	-0.11	0.39	-0.17	0.33	0.24	0.05	0.18	0.5	-0.21	0.2	0.41	-0.08	0.06	0.05	-0.11	0.13	0	0.03
4	DE2006I: Proportion of Residents who are not EU Nationals and citizens of a country with a medium or low HDI	-0.11	-0.07	0.27	-0.26	0.47	-0.07	0.03	0.27	0.1	-0.14	-0.16	-0.07	-0.04	-0.58	0.08	-0.13	0.28	-0.13	-0.16	0.06	-0.06
5	DE3003I: Total number of households	0.01	-0.32	0.27	0.09	-0.16	0.41	0.24	-0.08	0.17	-0.41	0.14	0.11	-0.12	0.11	0.1	0.35	0.2	-0.07	-0.3	0.06	0.17
6	DE3004I: Average size of households	0.09	0.25	-0.12	-0.4	-0.38	0.17	0.03	0.16	0.16	0.11	0	0.05	0.32	-0.02	-0.3	0.02	0.15	-0.54	-0.11	0.02	-0.01
7	DE3005I: Prop. of households that are lone-parent households	0.03	-0.04	0.44	0.35	0	0.05	-0.15	-0.02	0	0.25	-0.16	-0.09	0.47	0.03	-0.26	0	0.25	0.2	-0.18	-0.37	-0.01
8	DE3008I: Prop. households that are lone-pensioner households	-0.4	-0.12	0.03	0.09	0.14	0.21	-0.2	-0.06	0.14	-0.01	-0.08	-0.21	-0.13	0.11	-0.12	0.01	-0.47	-0.32	-0.22	-0.15	-0.45
9	EC1020I: Unemployment rate	-0.08	0.13	0.14	-0.19	-0.04	-0.23	-0.49	-0.25	-0.2	-0.49	0.27	-0.17	0.19	0.19	0.08	-0.06	0.25	-0.03	0	0.08	-0.18
10	EC3039I: Median disposable annual household income (city or NUTS 3 region)	0.44	0.03	-0.18	-0.05	0.1	-0.16	0.02	-0.22	0.15	0.02	0.24	-0.14	-0.16	-0.01	0.06	-0.3	-0.08	-0.04	-0.57	-0.34	0.15
11	EN5001I: Green space (in m2) to which the public has access per capita	-0.18	0.24	0.05	0.12	-0.19	0.03	0.28	0.17	-0.55	-0.06	0.44	0.07	-0.08	-0.32	-0.18	0.03	-0.09	0.11	-0.2	-0.13	-0.18
12	EN5012I: Proportion of the area in green space	-0.08	0.32	-0.05	0.16	-0.03	0.1	0.47	-0.17	0.07	-0.27	-0.25	-0.57	-0.02	0.08	-0.16	-0.26	0.13	0.04	0.1	0.1	0.02
13	EN5101I: Population density: total resident pop. per square km	-0.04	-0.12	-0.3	-0.48	0.16	0.29	-0.06	0.03	-0.02	-0.22	-0.08	-0.05	0.08	0	-0.35	0.14	-0.05	0.49	0.04	-0.31	0.06
14	SA1012I: Proportion of households living in social housing	0.29	0.04	0.15	0.12	0.2	0.17	-0.3	0.21	-0.35	-0.04	-0.05	-0.16	-0.38	0.12	-0.38	0.04	-0.01	-0.26	0.11	0.07	0.35
15	SA1018I: Proportion of dwellings lacking basic amenities	-0.05	-0.02	0.03	0.04	-0.38	-0.33	-0.08	0.62	0.22	-0.22	-0.09	-0.2	-0.21	0.11	0.13	0.05	0	0.07	0.04	-0.36	0.02
16	SA2016I: Mortality rate for <65 per year	-0.44	0.12	0.21	-0.06	-0.05	-0.04	-0.08	0.02	0.14	-0.08	0.09	0.16	0.14	0.01	-0.08	-0.33	-0.35	0.08	-0.11	0.11	0.62
17	SA2029I: Crude death rate per 1000 residents	-0.32	-0.01	-0.03	0.01	-0.13	-0.1	-0.15	-0.28	0.33	0.28	0.28	-0.09	-0.44	-0.19	-0.31	0.1	0.37	0.06	0.13	-0.04	0.07
18	SA3001I: Total Number of recorded crimes per 1000 population	-0.1	-0.33	0.08	-0.2	-0.16	-0.34	0.18	-0.33	-0.34	0.03	-0.23	-0.24	0.07	-0.17	0.03	0.27	-0.14	-0.26	0.07	-0.23	0.26
19	TE2025I: Prop. of working age population qualified at level 1 or 2 ISCED	0.06	0.23	0.34	-0.39	-0.12	0.1	-0.04	0.03	-0.04	0.38	-0.05	-0.35	-0.15	0.12	0.23	0.23	-0.12	0.29	-0.24	0.28	-0.03
20	TE2028I: Prop. of working age population qualified at level 3 or 4 ISCED	-0.13	0.47	-0.25	0.2	0.3	-0.23	-0.04	0	0.09	-0.08	-0.1	0.05	0.09	0.03	0.02	0.62	0.02	-0.05	-0.24	0	0.17
21	TE2031I: Prop. of working age population qualified at level 5 or 6 ISCED	0	-0.41	-0.32	0.17	-0.16	-0.2	-0.11	0.16	-0.05	0.01	-0.04	-0.22	0.15	-0.1	-0.26	0	0.01	0.15	-0.35	0.54	-0.01

Table 4.15, which shows correlation between the principal components (PC1 to PC21) and each of the 21 original indicators, can be used to find which indicators dominate each of the principal components. It can be seen that on average, decreasing correlation between the indicators and the principal components is found for increasing principal component number.

Table 4.15 Correlation between principal components (PC1 to PC21) and each of the original indicators. Green: Strong positive correlation. Yellow: Low correlation. Red: Strong negative correlation.

	INDICAOTRS	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11
1	DE1003I: Proportion of females to males in total population	-0.31	-0.05	-0.50	0.20	-0.02	0.51	-0.26	0.11	-0.10	0.13	0.16
2	DE1040I: Proportion of total population aged 0-4	0.73	0.08	0.29	0.13	-0.04	-0.01	-0.06	-0.05	0.33	-0.15	0.25
3	DE2005I: Proportion of Residents who are not EU Nationals and citizens of a country with high HDI	-0.20	-0.34	0.07	-0.15	0.48	-0.20	0.37	0.25	0.05	0.16	0.42
4	DE2006I: Proportion of Residents who are not EU Nationals and citizens of a country with a medium or low HDI	-0.22	-0.11	0.42	-0.34	0.58	-0.09	0.03	0.29	0.10	-0.12	-0.13
5	DE3003I: Total number of households	0.02	-0.53	0.42	0.12	-0.20	0.49	0.26	-0.09	0.17	-0.37	0.12
6	DE3004I: Average size of households	0.17	0.40	-0.18	-0.53	-0.46	0.20	0.03	0.18	0.16	0.10	0.00
7	DE3005I: Prop. of households that are lone-parent households	0.07	-0.06	0.68	0.47	0.00	0.06	-0.17	-0.02	0.00	0.23	-0.13
8	DE3008I: Prop. households that are lone-pensioner households	-0.80	-0.19	0.05	0.12	0.16	0.25	-0.22	-0.06	0.14	-0.01	-0.07
9	EC1020I: Unemployment rate	-0.16	0.20	0.23	-0.26	-0.05	-0.27	-0.54	-0.27	-0.20	-0.45	0.23
10	EC3039I: Median disposable annual household income (for city or NUTS 3 region)	0.88	0.05	-0.28	-0.07	0.12	-0.18	0.02	-0.24	0.14	0.02	0.20
11	EN5001I: Green space (in m2) to which the public has access per capita	-0.36	0.40	0.08	0.15	-0.23	0.04	0.31	0.19	-0.54	-0.05	0.37
12	EN5012I: Proportion of the area in green space	-0.16	0.53	-0.08	0.21	-0.03	0.12	0.52	-0.18	0.07	-0.25	-0.21
13	EN5101I: Population density: total resident pop. per square km	-0.08	-0.20	-0.48	-0.64	0.19	0.35	-0.07	0.04	-0.02	-0.20	-0.07
14	SA1012I: Proportion of households living in social housing	0.59	0.06	0.23	0.16	0.24	0.20	-0.34	0.23	-0.35	-0.04	-0.04
15	SA1018I: Proportion of dwellings lacking basic amenities	-0.10	-0.04	0.05	0.05	-0.46	-0.39	-0.08	0.67	0.21	-0.20	-0.07
16	SA2016I: Mortality rate for <65 per year	-0.88	0.20	0.33	-0.08	-0.06	-0.04	-0.09	0.03	0.14	-0.08	0.07
17	SA2029I: Crude death rate per 1000 residents	-0.63	-0.02	-0.05	0.01	-0.16	-0.12	-0.16	-0.30	0.32	0.26	0.23
18	SA3001I: Total Number of recorded crimes per 1000 population	-0.20	-0.54	0.12	-0.27	-0.20	-0.41	0.20	-0.36	-0.33	0.03	-0.19
19	TE2025I: Prop. of working age population qualified at level 1 or 2 ISCED	0.11	0.38	0.54	-0.52	-0.14	0.12	-0.04	0.03	-0.04	0.35	-0.04
20	TE2028I: Prop. of working age population qualified at level 3 or 4 ISCED	-0.27	0.77	-0.40	0.27	0.37	-0.27	-0.05	0.00	0.09	-0.08	-0.09
21	TE2031I: Prop. of working age population qualified at level 5 or 6 ISCED	-0.01	-0.68	-0.50	0.23	-0.19	-0.24	-0.12	0.18	-0.05	0.00	-0.03

	INDICAOTRS	PC12	PC13	PC14	PC15	PC16	PC17	PC18	PC19	PC20
1	DE1003I: Proportion of females to males in total population	-0.30	0.14	-0.14	0.29	0.01	0.07	-0.05	-0.03	-0.04
2	DE1040I: Proportion of total population aged 0-4	-0.17	0.16	-0.28	-0.07	-0.13	-0.22	0.02	-0.12	0.02
3	DE2005I: Proportion of Residents who are not EU Nationals and citizens of a country with high HDI	-0.17	0.15	0.28	-0.05	-0.04	0.03	-0.06	-0.05	0.00
4	DE2006I: Proportion of Residents who are not EU Nationals and citizens of a country with a medium or low HDI	-0.05	-0.03	-0.40	0.05	0.07	0.15	-0.07	0.06	0.02
5	DE3003I: Total number of households	0.09	-0.09	0.08	0.07	-0.20	0.11	-0.04	0.11	0.02
6	DE3004I: Average size of households	0.04	0.25	-0.01	-0.19	-0.01	0.08	-0.28	0.04	0.01
7	DE3005I: Prop. of households that are lone-parent households	-0.08	0.37	0.02	-0.16	0.00	0.13	0.10	0.07	-0.11
8	DE3008I: Prop. households that are lone-pensioner households	-0.17	-0.10	0.07	-0.08	-0.01	-0.26	-0.16	0.08	-0.04
9	EC1020I: Unemployment rate	-0.13	0.14	0.13	0.05	0.04	0.13	-0.02	0.00	0.03
10	EC3039I: Median disposable annual household income (for city or NUTS 3 region)	-0.12	-0.12	-0.01	0.04	0.18	-0.04	-0.02	0.21	-0.10
11	EN5001I: Green space (in m2) to which the public has access per capita	0.05	-0.06	-0.22	-0.11	-0.02	-0.05	0.05	0.07	-0.04
12	EN5012I: Proportion of the area in green space	-0.46	-0.01	0.05	-0.10	0.15	0.07	0.02	-0.04	0.03
13	EN5101I: Population density: total resident pop. per square km	-0.04	0.06	0.00	-0.22	-0.08	-0.03	0.25	-0.01	-0.09
14	SA1012I: Proportion of households living in social housing	-0.13	-0.29	0.09	-0.24	-0.02	0.00	-0.13	-0.04	0.02
15	SA1018I: Proportion of dwellings lacking basic amenities	-0.16	-0.16	0.08	0.08	-0.03	0.00	0.04	-0.02	-0.11
16	SA2016I: Mortality rate for <65 per year	0.13	0.11	0.01	-0.05	0.19	-0.19	0.04	0.04	0.03
17	SA2029I: Crude death rate per 1000 residents	-0.07	-0.34	-0.13	-0.19	-0.06	0.20	0.03	-0.05	-0.01
18	SA3001I: Total Number of recorded crimes per 1000 population	-0.19	0.05	-0.12	0.02	-0.16	-0.08	-0.13	-0.03	-0.07
19	TE2025I: Prop. of working age population qualified at level 1 or 2 ISCED	-0.28	-0.12	0.08	0.14	-0.13	-0.06	0.15	0.09	0.08
20	TE2028I: Prop. of working age population qualified at level 3 or 4 ISCED	0.04	0.07	0.02	0.01	-0.36	0.01	-0.02	0.09	0.00
21	TE2031I: Prop. of working age population qualified at level 5 or 6 ISCED	-0.18	0.12	-0.07	-0.16	0.00	0.00	0.07	0.13	0.16

Analysing principal component number one it should be noted that less emphasis should be put on the median income indicator (EC3039I) as the data is believed to contain errors. Looking at strongly correlated indicators, it would seem that a high value of this principal component would be characteristic for a young population. Principal component no 1 is therefore subjectively termed *Proportion of young people*.

The results of a similar analysis for the first eight principal components, representing close to 75% of the variation in the data, can be found in

Table 4.16. Along with the subjective descriptor is listed the indicator most strongly correlated (either positive or negative) with the principal component and the corresponding correlation value.

Table 4.16 Subjective labelling of the first eight principal components representing close to 75% of the variation in the data

No	*Subjective descriptor for principal component*	*Strongest correlated indicator*	*Strongest correlation value*
1	Proportion of young people	SA2016I: Mortality rate for <65 per year	-0.88
2	Green, suburban, medium educated family area	TE2028I: Prop. of working age population qualified at level 3 or 4 ISCED	+0.77
3	Low education, single parent households	DE3005I: Prop. of households that are lone-parent households	+0.68
4	Suburban, well educated, single people	EN5101I: Population density: total resident pop. per square km	-0.64
5	Medium educated, small household, immigrant areas	DE2006I: Proportion of Residents who are not EU Nationals and citizens of a country with a medium or low HDI	+0.58
6	Large, male dominates districts with social problems	DE1003I: Proportion of females to males in total population	+0.51
7	Suburban districts with high employment	EC1020I: Unemployment rate	-0.54
8	Slum areas	SA1018I: Proportion of dwellings lacking basic amenities	+0.67

4.3.3 Comparison of city and sub-city data

Table 4.17 shows a comparison of correlation of data at city and sub-city level (Correlation at sub-city level from Table 4.13 minus correlation at city level from Table 4.7). Components where data were not available at sub-city level are marked with NA. Components with absolute value larger than 0.5 are marked in red. Components with absolute value between 0.2 and 0.5 are marked in yellow. Components with absolute value between 0.1 and 0.2 are unmarked (white background). Components with absolute value less than 0.1 are marked in green.

It can be seen from the table that although a majority of the data correlates similarly at city and sub-city level (green and white), still there are a significant number of variables that correlate somewhat (yellow) or highly (red) different at sub-city from city level.

Table 4.17 Comparison of correlation of data at city and sub-city level (Correlation at sub-city level from Table 4.13 minus correlation at city level from Table 4.7). Components where data were not available at sub-city level are marked with NA. Components with absolute value larger than 0.5 are marked in red. Components with absolute value between 0.2 and 0.5 are marked in yellow. Components with absolute value between 0.1 and 0.2 are unmarked (white background). Components with absolute value less than 0.1 are marked in green.

	INDICATOR	1	2	3	4	5	6	7	8	9	10	11
1	DE1003I: Proportion of females to males in total population	0.00	NA	0.12	0.12	-0.23	-0.01	0.06	-0.26	0.13	-0.35	0.32
2	DE1028V + DE1055V: Total Resident Population 65 and over	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3	DE1040I: Proportion of total population aged 0-4	0.12	NA	0.00	0.00	-0.09	0.14	-0.11	-0.15	-0.14	0.14	0.17
4	DE2005I: Proportion of Residents who are not EU Nationals and citizens of a country with high HDI	0.12	NA	0.00	0.00	-0.14	-0.19	0.00	0.11	0.15	0.15	-0.35
5	DE2006I: Proportion of Residents who are not EU Nationals and citizens of a country with a medium or low HDI	-0.23	NA	-0.09	-0.14	0.00	-0.16	-0.03	-0.14	0.14	0.09	-0.66
6	DE3003I: Total number of households	-0.01	NA	0.14	-0.19	-0.16	0.00	-0.07	0.15	0.09	-0.10	-0.60
7	DE3004I: Average size of households	0.06	NA	-0.11	0.00	-0.03	-0.07	0.00	-0.22	0.16	0.05	0.45
8	DE3005I: Prop. of households that are lone-parent households	-0.26	NA	-0.15	0.11	-0.14	0.15	-0.22	0.00	0.02	-0.39	-0.52
9	DE3008I: Prop. households that are lone-pensioner households	0.13	NA	-0.14	0.15	0.14	0.09	0.16	0.02	0.00	0.01	-0.63
10	EC1020I: Unemployment rate	-0.35	NA	0.14	0.15	0.09	-0.10	0.05	-0.39	0.01	0.00	-0.15
11	EC3039I: Median disposable annual household income (for city or NUTS 3 region)	0.32	NA	0.17	-0.35	-0.66	-0.60	0.45	-0.52	-0.63	-0.15	0.00
12	EC3057I: Percent. households with less than half nat.aver.income	-0.21	NA	-0.21	0.24	0.64	0.43	-0.85	0.23	-0.02	0.08	-1.24
13	EC3060I: Proportion of households reliant upon social security	0.07	NA	0.05	-0.09	0.07	-0.24	-0.14	-0.28	-0.04	0.43	0.56
14	EN5001I: Green space (in m2) to which the public has access per capita	0.12	NA	-0.14	0.15	0.05	-0.05	0.10	-0.03	0.09	0.01	-0.23
15	EN5012I: Proportion of the area in green space	0.22	NA	0.02	-0.02	0.08	0.25	0.14	0.00	-0.04	-0.12	0.13
16	EN5101I: Population density: total resident pop. per square km	0.18	NA	-0.15	-0.13	-0.32	-0.43	0.17	-0.34	0.24	-0.01	0.09
17	SA1012I: Proportion of households living in social housing	0.19	NA	-0.14	0.03	0.22	-0.03	-0.05	0.10	-0.01	0.22	-0.33
18	SA1018I: Proportion of dwellings lacking basic amenities	-0.61	NA	0.20	0.06	-0.05	-0.24	0.33	-0.14	-0.36	0.16	0.09
19	SA2016I: Mortality rate for <65 per year	-0.43	NA	-0.07	0.20	0.19	0.06	0.24	0.06	0.27	0.32	-0.27
20	SA2029I: Crude death rate per 1000 residents	-0.13	NA	0.11	-0.09	-0.10	-0.01	0.26	0.06	-0.11	0.23	-0.24
21	SA3001I: Total Number of recorded crimes per 1000 population	0.00	NA	-0.38	-0.08	-0.05	-0.04	0.33	-0.27	-0.05	0.00	-0.52
22	TE2025I: Prop. of working age population qualified at level 1 or 2 ISCED	-0.11	NA	0.15	-0.14	0.08	-0.07	0.01	0.20	0.13	0.04	-0.77
23	TE2028I: Prop. of working age population qualified at level 3 or 4 ISCED	-0.25	NA	-0.02	-0.02	-0.07	-0.30	0.27	-0.31	-0.14	-0.05	0.73
24	TE2031I: Prop. of working age population qualified at level 5 or 6 ISCED	0.15	NA	-0.21	0.20	0.03	-0.16	-0.13	0.08	0.27	-0.26	0.53

	INDICATOR	12	13	14	15	16	17	18	19	20	21	22	23	24
1	DE1003I: Proportion of females to males in total population	-0.21	0.07	0.12	0.22	0.18	0.19	-0.61	-0.43	-0.13	0.00	-0.11	-0.25	0.15
2	DE1028V + DE1055V: Total Resident Population 65 and over	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3	DE1040I: Proportion of total population aged 0-4	-0.21	0.05	-0.14	0.02	-0.15	-0.14	0.20	-0.07	0.11	-0.38	0.15	-0.02	-0.21
4	DE2005I: Proportion of Residents who are not EU Nationals and citizens of a country with high HDI	0.24	-0.09	0.15	-0.02	-0.13	0.03	0.06	0.20	-0.09	-0.08	-0.14	-0.02	0.20
5	DE2006I: Proportion of Residents who are not EU Nationals and citizens of a country with a medium or low HDI	0.64	0.07	0.05	0.08	-0.32	0.22	-0.05	0.19	-0.10	-0.05	0.08	-0.07	0.03
6	DE3003I: Total number of households	0.43	-0.24	-0.05	0.25	-0.43	-0.03	-0.24	0.06	-0.01	-0.04	-0.07	-0.30	-0.16
7	DE3004I: Average size of households	-0.85	-0.14	0.10	0.14	0.17	-0.05	0.33	0.24	0.26	0.33	0.01	0.27	-0.13
8	DE3005I: Prop. of households that are lone-parent households	0.23	-0.28	-0.03	0.00	-0.34	0.10	-0.14	0.06	0.06	-0.27	0.20	-0.31	0.08
9	DE3008I: Prop. households that are lone-pensioner households	-0.02	-0.04	0.09	-0.04	0.24	-0.01	-0.36	0.27	-0.11	-0.05	0.13	-0.14	0.27
10	EC1020I: Unemployment rate	0.08	0.43	0.01	-0.12	-0.01	0.22	0.16	0.32	0.23	0.00	0.04	-0.05	-0.26
11	EC3039I: Median disposable annual household income (for city or NUTS 3 region)	-1.24	0.56	-0.23	0.13	0.09	-0.33	0.09	-0.27	-0.24	-0.52	-0.77	0.73	0.53
12	EC3057I: Percent. households with less than half nat.aver.income	0.00	-0.19	0.09	-0.07	0.58	0.22	0.13	0.06	-0.01	0.21	NA	NA	NA
13	EC3060I: Proportion of households reliant upon social security	-0.19	0.00	-0.42	-0.05	0.34	0.12	0.18	-0.52	-0.22	-0.10	NA	NA	NA
14	EN5001I: Green space (in m2) to which the public has access per capita	0.09	-0.42	0.00	0.10	-0.30	-0.08	0.13	0.43	0.16	0.06	0.33	0.09	-0.38
15	EN5012I: Proportion of the area in green space	-0.07	-0.05	0.10	0.00	0.08	0.11	0.17	0.33	0.15	-0.27	0.43	0.21	-0.27
16	EN5101I: Population density: total resident pop. per square km	0.58	0.34	-0.30	0.08	0.00	-0.30	0.00	-0.06	-0.20	0.08	-0.53	-0.13	0.42
17	SA1012I: Proportion of households living in social housing	0.22	0.12	-0.08	0.11	-0.30	0.00	0.17	-0.24	-0.17	-0.37	0.11	-0.21	-0.32
18	SA1018I: Proportion of dwellings lacking basic amenities	0.13	0.18	0.13	0.17	0.00	0.17	0.00	-0.39	-0.32	0.09	0.32	-0.38	0.02
19	SA2016I: Mortality rate for <65 per year	0.06	-0.52	0.43	0.33	-0.06	-0.24	-0.39	0.00	0.00	0.16	0.40	-0.29	0.00
20	SA2029I: Crude death rate per 1000 residents	-0.01	-0.22	0.16	0.15	-0.20	-0.17	-0.32	0.00	0.00	-0.04	0.08	-0.15	0.45
21	SA3001I: Total Number of recorded crimes per 1000 population	0.21	-0.10	0.06	-0.27	0.08	-0.37	0.09	0.16	-0.04	0.00	0.31	-0.46	0.38
22	TE2025I: Prop. of working age population qualified at level 1 or 2 ISCED	NA	NA	0.33	0.43	-0.53	0.11	0.32	0.40	0.08	0.31	0.00	0.09	-0.33
23	TE2028I: Prop. of working age population qualified at level 3 or 4 ISCED	NA	NA	0.09	0.21	-0.13	-0.21	-0.38	-0.29	-0.15	-0.46	0.09	0.00	-0.19
24	TE2031I: Prop. of working age population qualified at level 5 or 6 ISCED	NA	NA	-0.38	-0.27	0.42	-0.32	0.02	0.00	0.45	0.38	-0.33	-0.19	0.00

4.4 SUMMARY AND RECOMMENDATIONS

The objective of the work reported herein has been to review the only publicly available pan-European socio-economic indicator database, the European Urban Audit. The review has attempted to identify indicators suitable to describe levels of socio-economic vulnerability related to the need for emergency shelter as well as pressure on and functioning of the health system in a post-earthquake situation. In the downloaded Urban Audit data set, a total of 958 indicators are included grouped as follows:

- Demography (DE)
- Economic aspects (EC)
- Environment (EN)
- Social aspects (SE)
- Training and education (TE)

Out of the 958 indicators, data are collected for only 44 indicators. For these 44 indicators, data has been collected for two periods, 1999-2002 and 2003-2006. During the first period, data has been collected for 7856 districts in 321 cities in 30 European countries. During the second period, data has been collected for 2972 districts in 173 cities in 24 European Countries. Identification of indicators has been made through the following procedure:

1. Removal of indicators with no or very little data. A subjective selection procedure considering the relevance of the indicators to emergency shelter and health has been carried out. The resulting matrix with 44 indicators, organised with indicator as column heading and district as row heading, had completeness degrees of 32 % for 1999-2002 and 35% for 2003-2006.
2. Improving completeness: To improve completeness of the data set, the following procedure of excluding cities and indicators have been performed:
    a. Sort indicators according to completeness, i.e. starting with the indicator having data for the most districts and ending with the indicator having the least data.
    b. Subjectively exclude indicators with the least data. Indicators believed to carry information with significant importance for socio economic vulnerability should be kept when possible.
    c. Sort cities according to completeness, i.e. starting with the city having data for the most indicators and ending with the city with data for the least indicators.
    d. Subjectively exclude cities with the least indicators. Cities believed to have high significance, for example being among the last cities of a country, or representing a certain size or type of city should be kept.
    e. If necessary, repeat the procedure.

    Analysis was carried out both at city and sub-city district level for 2003-2006. At city level a total of 29 indicators was included, whereas 24 indicators were included at sub-city district level.
3. Correlation analysis and removal of highly correlated indicators. Five indicators were removed at city level, leaving 24 indicators for further analysis. At sub-city district level, three indicators were removed leaving 21 indicators for further analysis.

4. Principal component analysis with the objective to reduce the dimensionality of the data set while retaining as much as possible of the variation present in the data set. This was achieved by transforming the data to a new set of variables, the principal components (PCs), which are uncorrelated, and which are ordered so that the first few retain most of the variation present in all of the original variables. The city level data are represented by the first eight principal components representing close to 75% of the variation in the 24 original indicators. At sub-city district level, the same is found with the first eight principal components representing close to 75% of the variation in the data. It should be noted that the eight principal components at sub-city district level are not the same as the ones identified at city level.

It is expected that Urban Audit Data for the period 2007-2010 will be made available shortly, however as of January 2013 this data can not be downloaded from the Urban Audit website. These data will have to be analyzed following the same procedure to be able to identify data gaps and patterns of variation in the data. For 2003-2006, the following principal components are found to represent the Urban Audit Data well in terms of its relevance to socio-economic vulnerability considering emergency shelter and health care needs:

Table 4.18 Principal components representing the Urban Audit Data well in terms of its relevance to socio-economic vulnerability considering emergency shelter and health care needs: City level

No	*Subjective descriptor for principal component*	*Strongest correlated indicator*	*Strongest correlation value*
1	Proportion of poor people	SA2016I: Mortality rate for <65 per year	+0.69
2	Proportion of old people	DE1028V + DE1055V: Total Resident Population 65 and over	+0.73
3	Proportion of uneducated people	TE2025I: Prop. of working age population qualified at level 1 or 2 ISCED	+0.69
4	Proportion of households that are lone-parent households	DE3005I: Prop. of households that are lone-parent households	+0.76
5	Size of sub-city district	DE3003I: Total number of households	+0.55
6	Proportion of highly educated people	TE2031I: Prop. of working age population qualified at level 5 or 6 ISCED	+0.66
7	Crude death rate per 1000 residents	SA2029I: Crude death rate per 1000 residents	+0.48
8	Population density	EN5101I: Population density: total resident pop. per square km	+0.46

Table 4.19 Principal components representing the Urban Audit Data well in terms of its relevance to socio-economic vulnerability considering emergency shelter and health care needs: Sub-city district level

No	*Subjective descriptor for principal component*	*Strongest correlated indicator*	*Strongest correlation value*
1	Proportion of young people	SA2016I: Mortality rate for <65 per year	-0.88
2	Green, suburban, medium educated family area	TE2028I: Prop. of working age population qualified at level 3 or 4 ISCED	+0.77
3	Low education, single parent households	DE3005I: Prop. of households that are lone-parent households	+0.68
4	Suburban, well educated, single people	EN5101I: Population density: total resident pop. per square km	-0.64
5	Medium educated, small household, immigrant areas	DE2006I: Proportion of Residents who are not EU Nationals and citizens of a country with a medium or low HDI	+0.58
6	Large, male dominates districts with social problems	DE1003I: Proportion of females to males in total population	+0.51
7	Suburban districts with high employment	EC1020I: Unemployment rate	-0.54
8	Slum areas	SA1018I: Proportion of dwellings lacking basic amenities	+0.67

It should be noted that the subjective descriptors as given in the tables above should be used with care, and that a full understanding of each of the eight principal components included both at city and sub-city district level can only be obtained by considering how the individual indicators contribute to each principal component as detailed in Table 4.6 (city level) and Table 4.12 (sub-city district level).

5 Transportation accessibility model

5.1 BACKGROUND AND INTRODUCTION

5.1.1 Introduction

Earthquakes often cause high degree of displacement within affected populations. Especially in high density urban areas, the amount of the affected population is much higher. The main goal of disaster management is to minimize the total number of affected population. In this context, GIS based accessibility modelling can be an important guide for disaster managers to decrease the amount of affected population, before, during and after disaster. As the amount of available resources are limited and disaster managers always have to decide the optimal location and capacity of available resources in the territory by considering location and capacity of demand locations, GIS based accessibility modelling can directly provide a vital support in terms of accessibility, location/allocation and service/catchment related issues. For example; GIS based accessibility modelling can directly help determination of location and capacity of mobile hospitals, search-and-rescue (SAR) teams, equipment storage depots, temporal living depots etc.

Although there are many researchers interested in resource location/allocation problem in disaster case, most of them are focusing on the location/allocation problem as a theoretical optimization problem without considering the GIS based decision-support aspect of the issue. The literature that integrates location/allocation optimization process with GIS based decision support as an accessibility modelling tool is quite limited which can be considered as a significant lack in terms of providing active decision support for the decision makers in earthquake case.

5.1.2 GIS based accessibility modelling techniques

Since physical accessibility measures describe the spatial characteristics of a location and need large amount of computation and organization between huge and complex spatial data sets, accessibility modelling often and unavoidably lends itself to Geographical Information Systems technologies in terms of data collection, manipulation, programming, topology, analysis and presentation related issues.

As GIS have unique capabilities to handle spatial data and operations related to positions on the Earth's surface, with an integrated database of basic transportation, land-use and socio-economical data, GIS could provide a powerful interface and infrastructure for the decision makers who are supposed to deal with accessibility, location/allocation and service/catchment area related issues. As accessibility measures such as transportation, land use and/or socio-economical data, accessibility modelling needs a GIS environment. The literature on GIS based accessibility modelling techniques can generally be divided into three, which are listed below and described in detail in Makrí and Folkesson (1999), Juliao (1999), and Chen (2000).

- Zone-based technique
- Isochronal (isochrone based) technique

- Raster based technique

In zone-based technique, calculated accessibility measures are represented inside the defined bordered zones such as states, countries, metropolitan areas, districts, quarters or any catchment/service areas. Determination of the size of the bordered zones is generally determined by the aim, the obtained data and the detail needs of the study. While a national or regional scale accessibility study generally requires a coarse zone representation such as state, country or district boundaries, a local scale accessibility study can require a smaller zone representation such as quarter or parcel boundaries. However, it must also be taken into consideration that the data is more difficult to obtain for the smaller zones such as parcels and quarters when compared to coarse zones such as districts and countries (Halden et al. 2000).

Zone-based technique

In zone-based accessibility modelling technique, travelling cost calculation between supply and demand points are usually based on the zone centroids, which are geometric center of zones. In GIS environment, zonal centroids are generally used as representatives of the bordered zones (Fig. 5.1) and help to calculate travelling costs between supply and demand points. The zone based technique has the advantage of easier comparisons of accessibility scores between the bordered zones. However, two main disadvantages of this technique are that the whole area inside the zones are represented with the same accessibility value based on deterministic travelling costs such as “Euclidian distance costs” or “constant transportation network based costs” are used to model accessibility.

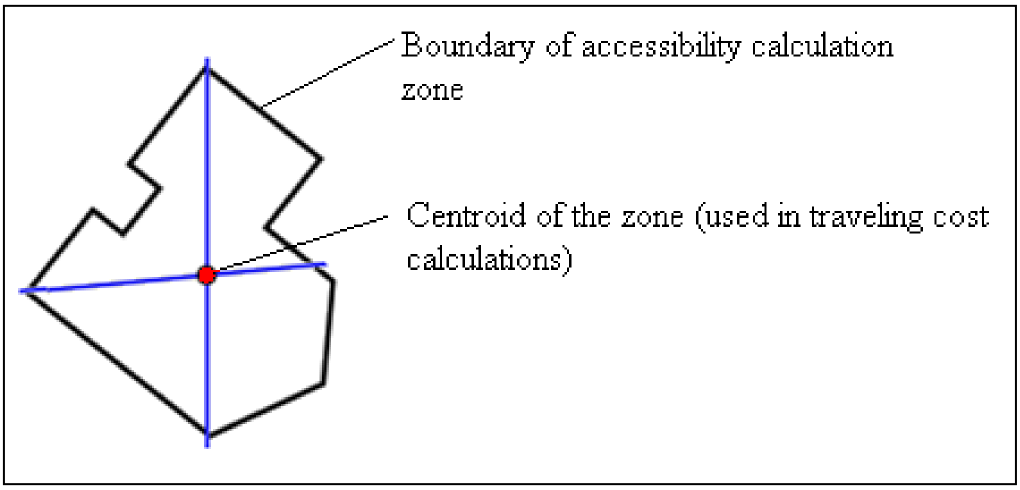


Fig. 5.1 Centroid of a zone

Isochronal (isochrone based) technique

In isochronal technique, accessibility measures are represented in terms of isochronal polygons, which are also known as the catchment or service area polygon boundaries. Isochronal polygon boundaries connect equal travel time or distance points away from one or more reference points (e.g. supply or demand). Isochrone-based accessibility polygon boundaries are calculated from either constant average transportation network based travelling costs such as 120 km/h for highways, 50 km/h for main streets and 30 km/h for local streets, etc. or unconstrained Eucledian distance based costs (straight-line/bird-flight based distances) such as buffer, voronoi (thiessen) polygons without considering the transportation network.

When an origin is defined as a reference point such as a demand or supply location, isochronal polygon boundaries can be drawn by connecting all points in all directions for an equal threshold of time or distance (Fig. 5.2).

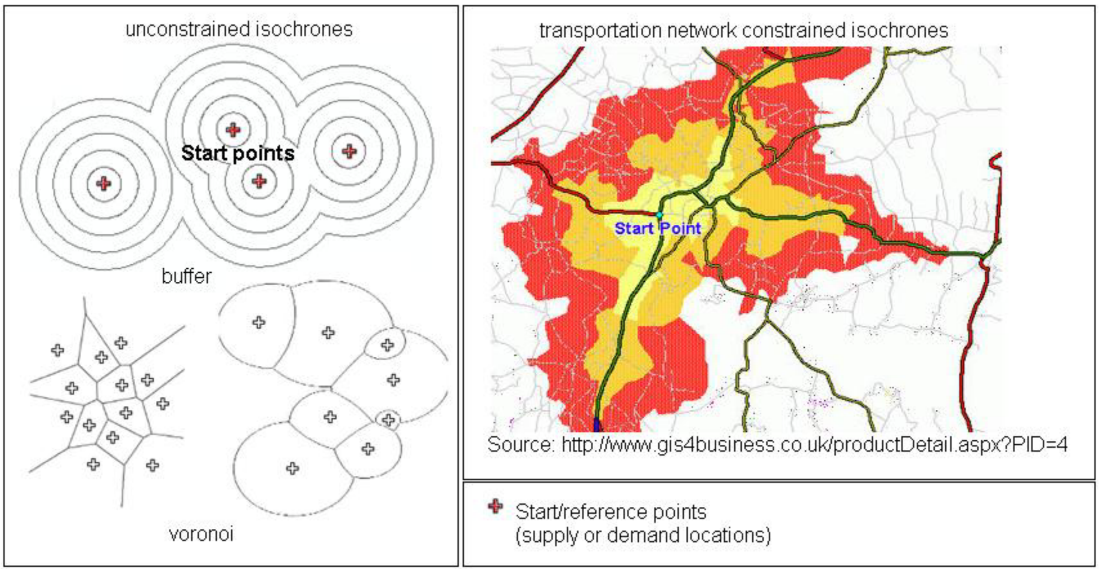


Fig. 5.2 The isochronal representation of accessibility (Source?)

The buffer and voronoi based isochrononal polygon boundaries have regular shape because of their unconstrained structure. However, transportation network based isochronal polygon boundaries are constrained by the transportation network and can have irregular shape as the costs in a transportation network can provide travelling faster in some directions and travelling slower in other directions (Transportation Statistics Annual Report, 1997).

Isochronal technique can be used in calculation of several accessibility measures ranging from simple to sophisticated. For example,

- 10 minutes catchment area polygon boundary of supply/demand points can be calculated as a travel time/distance type of measure or
- total number of cumulated supply/demand points within 10 minutes catchment boundary can be calculated as a cumulative opportunity type of measure or
- total number of weighted supply/demand points within 10 minutes catchment boundary can be calculated as a “gravity” type of measure etc.

Although isochronal based technique is widely used in accessibility modelling literature, one of the weaknesses of the isochronal technique is that accessibility measures are highly sensitive to travelling time/distance based costs and user defined thresholds. Slight changes in travelling costs and user-defined thresholds can create significant changes in catchment area polygon boundaries and hence directly affect the amount of supply and demand opportunities. Considering several costs and thresholds, can provide more realistic decision support for decision makers who are supposed to deal with accessibility, location/allocation and service/catchment area related issues.

Raster-based technique

“Pixel”, which is also called “cell”, can be defined as the smallest unit in raster environment. In raster-based technique, accessibility measures are represented by raster-based “pixels” instead of vector-based “polylines” or “polygons”. The supply and demand locations and the transportation network are the main inputs of raster-based technique. By considering travelling costs in the transportation network, each pixel in raster environment generally gets an accessibility score, which is based on its proximity to nearest supply or demand opportunity (Fig. 5.3). Raster-based technique is generally preferred in regional studies, which does not necessitate high spatial accuracy. Because of pixel-based structure of the raster-based technique, working in raster environment reduces the geometrical accuracy of accessibility measures. However, it enables continuous representation of accessibility scores and opens a wide range of new raster analysis capabilities.

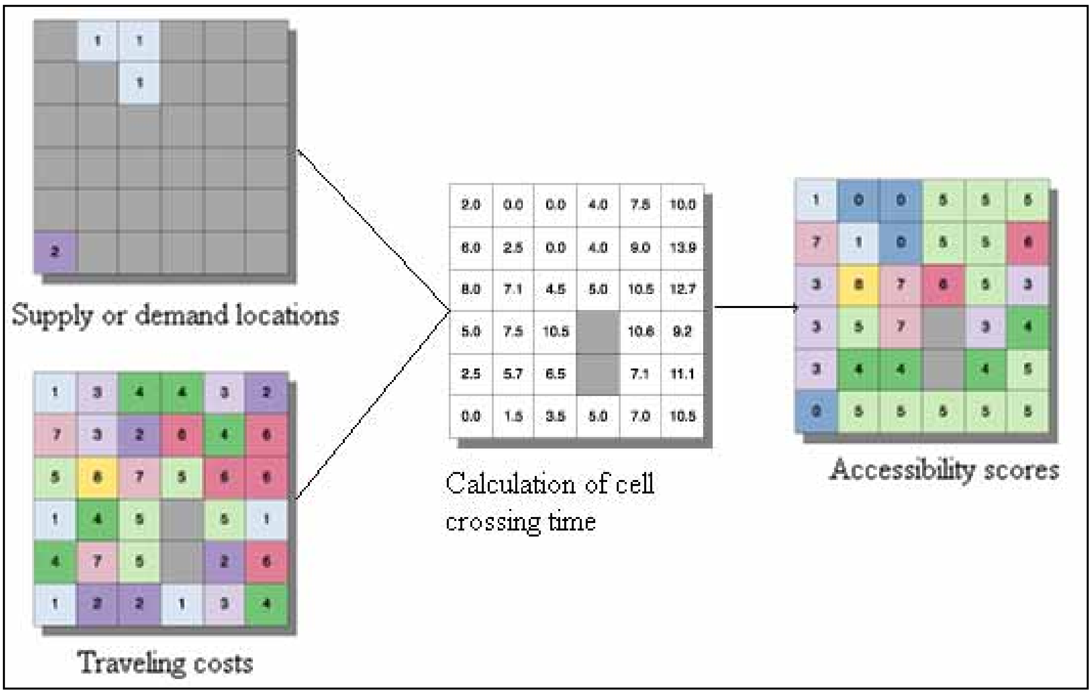


Fig. 5.3 The raster-based representation of accessibility, Source: ESRI (2011)

5.2 INDICATORS OF TRANSPORTATION ACCESSIBILITY

The term accessibility basically refers to people’s ability to reach intended goods, services and activities considering several travel costs and reflects the comparable ease for travellers (Kwan, 1998, Makri, 2002). Transportation accessibility is defined as people’s ability to reach services and activities in an urban environment. It is measured based on travel costs expressed in various ways and allows one to compare ease of travel in urban context. As many factors affect accessibility, different aspects and measures of accessibility are found in the literature. The report provides an overview of accessibility indicators which are grouped under twelve categories (Litman, 2011) and presented in

Table 5.1. Finally, an analysis of indicators with their relation to urban audit data is given.

Table 5.1 Factors affecting accessibility (Litman, 2011)

Name	Description	Current Consideration
Transport Demand	The amount of mobility and access that people and businesses would choose under various conditions (times, prices, levels of service, etc).	Motorized travel demand is well studied, but nonmotorized demand is not. Travel demand is often considered exogenous rather than affected by planning decisions.
Mobility	The distance and speed of travel, including *personal mobility* (measured as person-miles) and *vehicle mobility* (measured as vehicle-miles).	Conventional transport planning primarily evaluates mobility, particularly vehicle mobility.
Transportation Options	The quantity and quality of access options, including walking, cycling, ridesharing, transit, taxi, delivery services, and telecommunications. Qualitative factors include availability, speed, frequency, convenience, comfort, safety, price and prestige.	Motor vehicle options and quality are usually considered, using indicators such as roadway level-of-service, but other modes lack such indicators and some important service quality factors are often overlooked.
User information	The quality (convenience and reliability) of information available to users on their mobility and accessibility options.	Frequently considered when dealing with a particular mode or location, but often not comprehensive.
Integration	The degree of integration among transport system links and modes, including terminals and parking facilities.	Automobile transport is generally well integrated, but connections between other modes are often poorly evaluated.
Affordability	The cost to users of transport and location options relative to incomes.	Automobile operating costs and transit fares are usually considered.
Mobility Substitutes	The quality of telecommunications and delivery services that substitute for physical travel.	Not usually considered in transport planning.
Land Use Factors	Degree that factors such as land use density and mix affect accessibility.	Considered in land use planning, but less in transport planning.
Transport Network Connectivity	The density of connections between roads and paths, and therefore the directness by which people can travel between destinations.	Conventional planning seldom considers the effects of roadway connectivity on accessibility.
Roadway Design and Management	How road design and management practices affect vehicle traffic, mobility and accessibility.	Some factors are generally considered, but others are not.
Prioritization	Various strategies that increase transport system efficiency.	Often overlooked or undervalued in conventional planning.
Inaccessibility	The value of inaccessibility and isolated.	Not generally considered in transport planning.

In this report accessibility only due to urban land transportation is considered. Accessibility of harbours or accessibility by means of marine transportation is not taken into account. The main reason for this is that accessibility to residents of urban environment and accessibility of residents to critical services like fire brigades and health services at the neighbourhood scale has direct influence on social vulnerability. Accessibility of harbours or accessibility by means of marine transportation usually affects the transfer of goods to the urban area, which has indirect influence on social vulnerability. As many factors affect accessibility, different aspects and measures of accessibility are found in the literature. Accessibility can be evaluated from different perspectives, including various types of the traveller, transportation mode, land use etc.

Table 5.1 by Litman (2011) also lists these factors and the degree to which they are considered in current transport planning.

TRANSPORTATION DEMAND AND ACTIVITY refers to the amount of mobility and accessibility that people would choose under various travelling conditions such as time, price, congestion etc. Demographic and geographic factors directly affect transportation demand and activity. For example, attending school, being employed, or having dependents increases transportation demand. Travelling conditions such as frequency, time, price, congestion etc. are also other factors that affect transportation demand and activity (Litman, 2011). The indicators for transport demand and activity can be grouped into two:

- Demographic and geographic factors: These factors affect demand for mobility and access. Example of indicators include, attending school, being employed, or having dependents increases demand
- Price and quality related factors: These factors affect demand for each mode and mode split

Mobility refers to potential for movement (Transportation Statistics Annual Report, 1997). Increased mobility can mean more accessibility. The more and faster travel increase accessibility and people/services can reach more destinations (Krizek. et al., 2007, Litman, 2011).

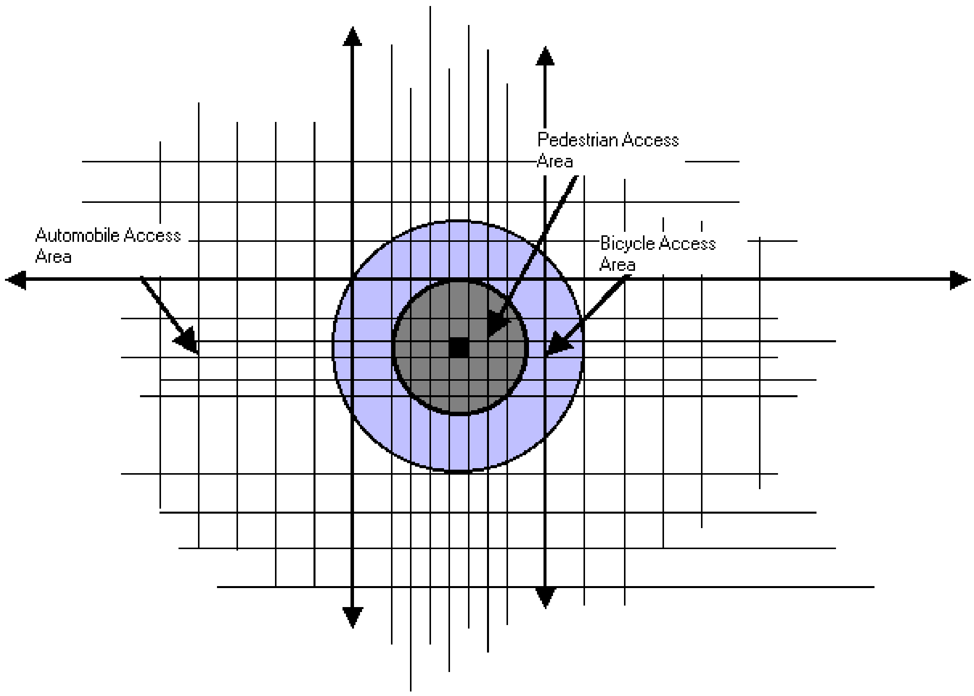


Fig. 5.4 Accessibility levels for various transportation means

Fig. 5.4 shows that increased speed can result in a proportionally larger increase in accessible area (Litman, 2011). The indicators for mobility can be grouped into three:

- Higher speed and faster travel: It increases accessibility
- Congestion: It limits accessibility by a particular mode

- Transportation type: Efforts to increase the use of cars can reduce other forms of accessibility

TRANSPORTATION OPTIONS (also called transportation diversity and choice) can be defined as the quantity and quality of transportation modes and services, including walking, cycling, public transportation, taxi, etc. The availability, speed, frequency, convenience, comfort, safety, price and prestige are also important. In general, improving transportation options improves accessibility. The indicators for transportation options can be grouped into two:

- Improved transport options: They tend to improve accessibility. Improvements can include increased convenience, speed, comfort, affordability, security, user information and prestige.
- Destinations served by more modes or better quality service: They tend to have better access.

USER INFORMATION can be defined as the quality (convenience and reliability) of any kind of travel related information such as maps, brochures, websites, telephones systems, navigations (GPS systems) and web pages available to travellers. The main indicator for user information is:

- The availability and accuracy of user information: They affect accessibility by improving user information is an effective way of improving accessibility. The effectiveness of such information depends on how well potential users are aware of, can access, and actually apply information (Litman, 2011).

INTEGRATION, TERMINALS AND PARKING is the degree of integration among several transportation system links and modes, such as bicycle, car, bus, train, airport and metro, including terminals and parking facilities. The indicators are:

- The connections between links and modes: They directly define accessibility.
- The location and quality of transportation terminals: They affect the accessibility of the modes they serve. The quality of bus stops, train stations, ferry terminals and other transfer facilities affects the relative accessibility of these modes.

AFFORDABILITY is the cost of travelling to users relative to their incomes. Automobile operating costs and transit fares are usually considered in this group. Drivers are primarily affected by the affordability of driving, while non-drivers are more affected by the affordability of alternative modes, such as public transit and taxi services. The main indicators are:

- Affordability: It is especially a problem for low-income groups. Affordability can be improved by reducing user costs (vehicle purchase costs, fuel prices, transit fares, etc.), by improving more affordable modes (such as walking, cycling and public transit), and by increasing land use accessibility.
- Location: It affects transport affordability. Lower-income residents in automobile-dependent locations tend to spend an excessive portion of their income on transport (Litman, 2011).

MOBILITY SUBSTITUTES is the quality of telecommunications and delivery services that substitute for physical travel. Mobility substitutes include telework (telecommunications that substitutes for physical travel) and delivery services that provide access with minimal mobility ("Telework" VTPI, 2006). Mobility substitutes can provide access for many goods and activities. For example, one way to improve access to information is to provide high-speed Internet service, and arrange convenient and inexpensive delivery of library books directly to homes. Similarly, pharmacies may deliver medicines and other medical goods, rather than requiring customers to travel to a store. However, there are limits to mobility substitute benefits. Many jobs and employees are unsuitable for telecommuting. Although it may be possible to purchase goods online, it is usually less satisfying than visiting a store where the physical goods can be examined (Litman, 2011). Mobility substitutes can provide access to certain types of activities (primarily involving information exchange), certain types of goods (suitable for shipping), and certain types of users (people who are comfortable using telecommunications equipment). They do not eliminate the need for other types of access, and by themselves may stimulate motorized travel by supporting more dispersed housing and long-distance commutes. As mobility substitutes can provide alternative modes by reducing vehicle travel, the presence and variety of these substitutes can be considered as the main indicator in evaluating the accessibility.

LAND USE FACTORS are related with the land use density, mixture, connectivity and walk ability (Litman, 2005). A more accessible land use pattern means that less mobility is needed to reach activities and destinations. The following are some types of landuse affecting accessibility:

- As destinations are located closer together along a roadway, accessibility increases.
- A more central location reduces travel requirements, increasing accessibility.
- A connected loop increases route options and hence increases accessibility. Locations close to crossroads reduces travel requirements and increases accessibility.
- The increased number of roadway connections leads to larger route options with increased accessibility.
- Clustering increases access to common activities, particularly by walking and public transit.
- Vertical clustering like multi-story buildings can increase accessibility.

The indicators of land use type are:

- Increased density and clustering of activities: They tend to increase accessibility.
- Shorter travel distances: They improve transport options (particularly walking).
- More connected road network: It increases accessibility.
- Clustering and mixing of common destinations: It increases accessibility.
- Clustering transportation services into centres and terminals: It increases accessibility.

TRANSPORTATION NETWORK CONNECTIVITY can be defined as the density of connections between roads and paths, and the directness by which people can travel between destinations. A connectivity index evaluates how well a roadway network connects destinations (Ewing, 1996). It is computed by dividing the number of roadway links by the number of roadway nodes. A higher index means that travellers have increased route choice, allowing more direct connections for access between any two locations (Litman 2011). Increased network connectivity tends to increase accessibility. A traditional grid network has many connected roads, providing multiple, direct route choices. This tends to reduce trip distances, increase travel choice, reduce congestion, and increase accessibility.

Furthermore, a hierarchical road network channels traffic onto a few major arterials, even for travel between destinations located near to each other. This tends to reduce accessibility, increase congestion and reduce travel options (particularly walking). This roadway design is common in suburban communities. Finally, a modified grid has many connected roads designed with short blocks and T-intersections to limit traffic speeds. Paths create shortcuts for walking and cycling. This provides good accessibility, creates a more liveable neighbourhood and encourages non-motorized transport.

The main indicators are:

- A hierarchical street system with traffic channelled onto major arterials: It tends to reduce access, increase congestion and degrade non-motorized travel conditions.
- A grid or modified grid street system: It provides more direct access to destinations.
- Pedestrian paths and shortcuts: It can improve non-motorized accessibility (Litman 2011).

Roadway Design and Management considers how road design and management practices affect traffic, mobility and accessibility. For example, wider and straighter roads with minimum intersections and driveways tend to favour automobile travel, but may be difficult and unpleasant for walking and cycling, and therefore for public transit access. Conversely, design and management strategies, such as expanding pedestrian and cycling facilities, traffic calming, and traffic speed reductions, tend to benefit walking and cycling access, but reduce motor vehicle traffic speeds and capacity, reducing mobility design and management factor (Litman, 2011). The main indicator for roadway design and management is the road geometry and fragility.

PRIORITIZATION considers various strategies that increase transportation system efficiency. Prioritization increases transport system efficiency by giving priority to higher value trips and more efficient modes. The following factors are indicators:

- Pricing: It allows a special type of traffic management based on travellers willingness-to-pay.
- Policies: Priority for emergency and freight vehicles in traffic, transit subsidies and special mobility services for people who travel to school and work, people with disabilities etc. are examples
- High Occupant Vehicle (HOV) priority systems: They give priority over space to space-efficient vehicles, such as vanpools and buses, when compared with inefficient vehicles in traffic.
- Location-efficient planning: It encourages major traffic generators (such as employment centres, public services, and large residential buildings) to choose more accessible locations (such as near transit centres and highway intersections, such as vanpools and buses, priority over space inefficient vehicles in traffic).
- Transportation planning practices: Transportation improvement options that are most cost effective overall, including alternative modes and demand management strategies), and congestion pricing (pricing designed to ration road space are examples (Litman 2011).

THE INACCESSIBILITY is the value of inaccessibility and isolation. For example, many people dream of living on an isolated rural community or island for the sake of quiet, privacy and community cohesion. Expanded transport facilities and increased vehicle traffic impose significant external costs such as increased infrastructure costs, congestion, accident risk, neighbourhood disruptions, energy consumption and pollution emissions, which may offset much of the benefits of increased mobility. Comprehensive analysis of accessibility and mobility should therefore account for these external costs, and not assume that increased accessibility and mobility are necessarily beneficial (Litman, 2011).

Based on the factors affecting the accessibility and related indicators,

Table 5.2 describes the relation between the urban audit data and its relevance to accessibility indicators. In Table 5.2 high, medium and low correlation between the urban audit data and transport accessibility are given to the right side of the audit data indicators as values “H” and “M” and “L”, respectively.

Among the various data groups in urban audit data, demography, economic aspects, environment, travel and transport, information society show higher correlation when assessing accessibility in urban environments. Hence by using these indicators relative accessibility levels of various urban environments can be assessed to be used in socio-economical vulnerability analysis.

Table 5.2 The Urban Audit Indicator’s relevance with physical accessibility

THE AUDIT DATA	RELATION WITH ACCESSIBILITY
Demography (DE)	
Population (DE1)	H
Nationality (DE2)	L
Household Structure (DE3)	H
Social Aspects (Sa)	
Housing (SA1)	M
Health (SA2)	L
Crime (SA3)	L
Economic Aspects (Ec)	
Labour Market (EC1)	H
Economic Activity (EC2)	H
Income Disparities And Poverty (EC3)	H
Civic Involvement (CI)	
Civic Involvement (CI1)	L
Local Administration (CI2)	H
Training And Education (TE)	
Education And Training Provision (TE1)	L
Educational Qualifications (TE2)	M
Environment (En)	
Climate/Geography (EN1)	H
Air Quality And Noise (EN2)	M

Water (EN3)	H
Waste Management (EN4)	L
Land Use (EN5)	H
Travel And Transport (TT)	
Travel Patterns (TT1)	H
Information Society (IT)	H
Users And Infrastructure (IT1)	
Local Government (IT2)	H
ICT Sector (IT3)	H
Culture And Recreation (Cr)	
Culture And Recreation (CR1)	M
Tourism (CR2)	H

5.3 DESCRIPTION OF METHODOLOGY

5.3.1 Accessibility for shelter model

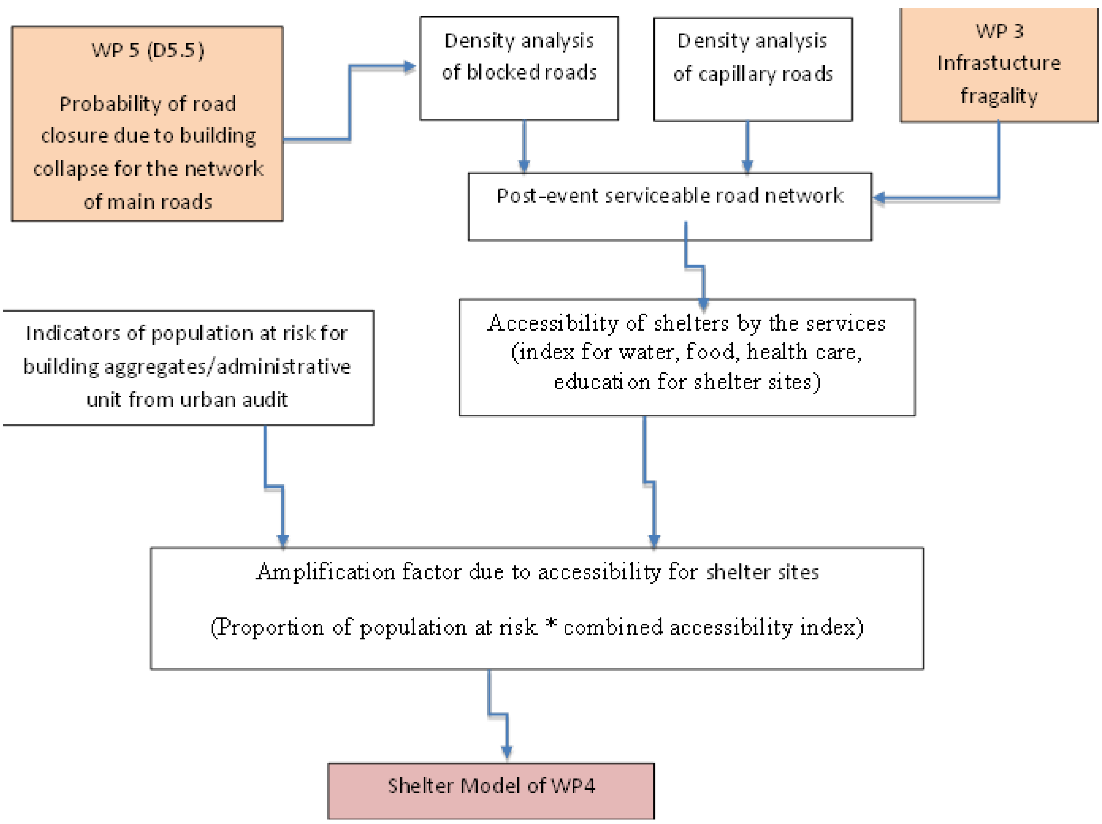


Fig. 5.5 Relation between Shelter Model and Accessibility

The accessibility to shelter areas from several services (accessibility to services like water, health, food etc. close the shelter area) will be taken into account. For this issue again certain accessibility indexes will be developed and combined in a single index. An overall accessibility within each administrative district will be determined for provision of shelter. In this analysis parameters like slope, road width, road blockage, open space area per person, etc. will be used and an accessibility score will be evaluated to the administrative unit for shelter sites determined from scenario analysis (Fig. 5.5).

5.3.2 Accessibility for health-care model

Accessibility is important in two ways for the health care model:

1. Accessibility of any health care facility from a given location in the urban area by the healthcare seekers and providers. In a crises management health care seekers may want to reach the health facilities on their own or may request ambulances or other transportation means.
2. Accessibility of any location in the urban area by the ambulances of health care units is also important for effective emergency response.

Depending on the road network condition after the earthquake, which will be predicted by fragility of transportation network in SYNER-G, the accessibility models will be developed and an accessibility index for each administrative unit will be obtained. Then the health care model will be amplified based on these indexes. In such analysis, for a given urban environment, an accessibility model can be obtained through any GIS software which has network modelling tools with a shortest path algorithm. WP4 will also provide a report on the software requirements, data requirement and the accessibility modelling approaches to achieve an accessibility index. Hence in WP4 the accessibility to health care facilities will be considered as an additional parameter to the structural, operational and organizational capacity of the health care centers. Here a scenario based analysis, where some field hospitals are assigned in the case studies will be followed and the overall picture of accessibility will be identified and reflected to health care model as an amplification factor

The accessibility models use out parameters from the SYNER-G Road Network Model developed in Technical Report D5.5 (Pinto et al,20120), based on the road system fragility functions developed in Technical Report D3.7 (Kaynia et al, 2011) as input parameters.

In order to take the fragility of the road infrastructure, it is necessary to know the spatial distribution of various infrastructure types and their vulnerability for the given seismic hazard. As such, a scenario-based damage states for the infrastructure is considered. Based on these two inputs (orange boxes in Fig. 5.5), first accessibility of capillary roads to main roads is analyzed. In this analysis the density of capillary roads is considered as accessibility from the main road network to the capillary road network density centers. Additionally post event serviceable road network will be identified by using the density of blocked roads, accessibility of capillary roads and infrastructure fragility (if given). Then based on D5.5 and the spatial locations of health care units, accessibility index for building aggregates and/or administrative units by the ambulance's, fire brigades' or rescue workers will be calculated as well as index of people's level of accessibility to the health care facilities by their own transportation means. The accessibility of healthcare units together with the healthcare capability indicators will provide the health care performance. Assessment of health care facility performance will be performed by using an Analytical Hierarchy (AHP) approach.

The weights of various criteria will be determined based on a matrix of health care facility accessibility and available services and fragility of health care facilities (Table 5.3).

Table 5.3 A matrix of health care facility accessibility and available services and fragility of health care facilities

Name of the hospital	Capability global_value	Accessibility level (time cost statistics in seconds to administrative zone centroids) minimum	maximum	average	sum
INFECTIOUS DISEASES HOSPITAL OF THESSALONIKI	1,5	213	869	486	2429
"IPPOKRATIO" HOSPITAL	6	237	797	487	2434
THEAGENIO ANTICANCER HOSPITAL	4,25	333	793	522	2608
GENERAL HOSPITAL OF THESSALONIKI "G. GENNIMATAS"	4	82	1055	555	2776
REGIONAL GENERAL HOSPITAL OF THESSALONIKI "AHEPA "	5,5	200	989	556	2779
APHRODISIAC AND SKIN DISEASE HOSPITAL	1,5	146	1021	581	2905
GENERAL HOSPITAL OF THESSALONIKI "AG. APVLOS"	3,5	467	1417	863	4315
PSHYCHIATRIC HOSPITAL OF THESSALONIKI	2,75	607	1697	1072	5358
GENERAL REGIONAL HOSPITAL "PAPAGEORGIOU"	4,5	1012	1763	1263	6314
GENERAL REGIONAL HOSPITAL "PAPANIKOLAOU"	5	1870	2480	2091	10456

With AHP the health care facility performance will be determined. The combined accessibility index for the urban environment and the percentage of population at risk in the building aggregates/administrative units will be used for evaluating the required amplification factor to be used in health care model of WP4 (Fig. 5.6).

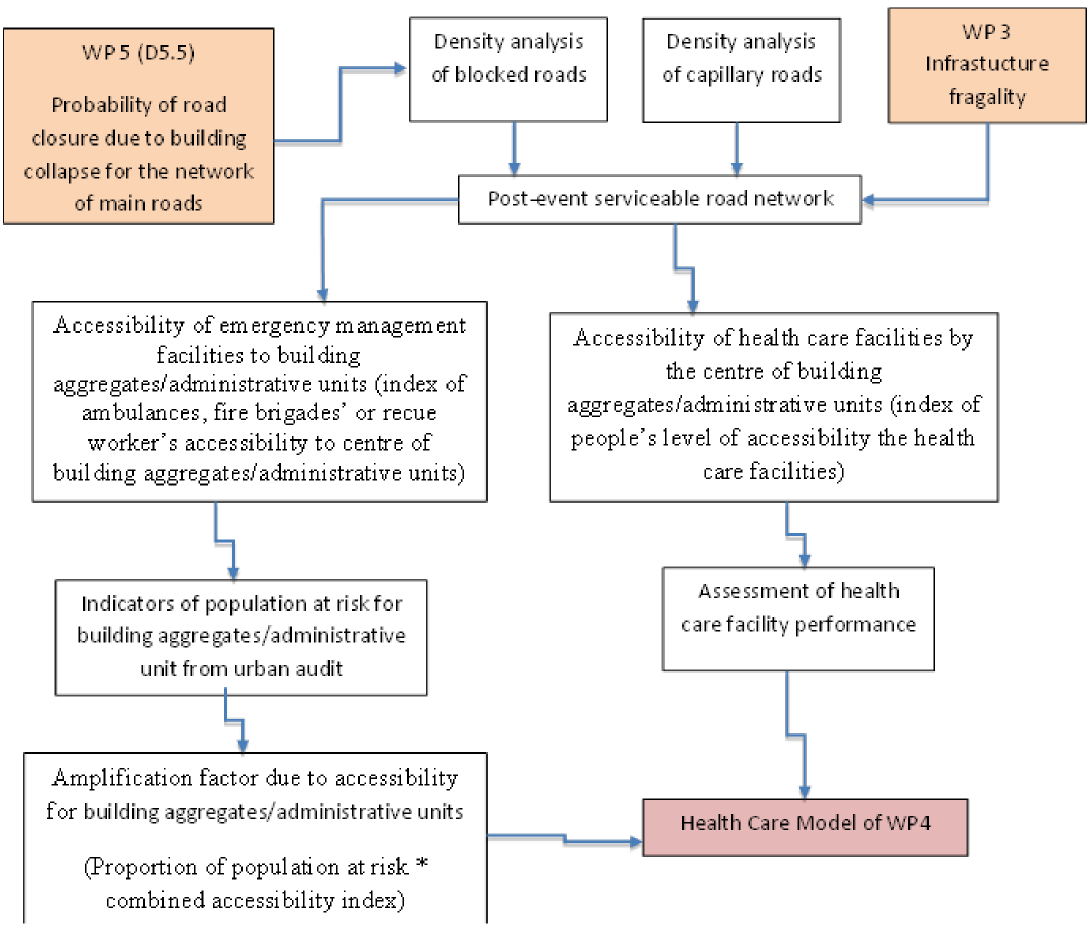


Fig. 5.6 Relation between Health Care Model and Accessibility

5.4 ACCESSIBILITY MODEL IMPLEMENTATION

Using the approach described, an accessibility model is implemented in the city of Thessaloniki. The implementation of the transportation accessibility model consists of three steps, which are;

- data acquisition and integration
- transportation network based travelling cost calculation
- accessibility modelling and visualization

Data acquisition and integration phase includes preparation of data in which supply/demand locations and transportation network data are obtained and converted into a common GIS format. Transportation network based travelling cost calculation phase includes determination of travelling costs for each of the road segment on the transportation network according to road closure probabilities that comes from WP5 (Pinto et al., 2012). Finally, accessibility modelling and visualization phase includes measurement and representation of accessibility scores in GIS environment.

The basic data used in the model are;

- GIS based digital transportation network data of Thessaloniki (line)
- GIS based health service locations data of Thessaloniki (point)
- GIS based shelter service locations data of Thessaloniki (point)
- GIS based administrative borders of Thessaloniki (area)

In the transportation network based travelling cost calculation phase, for the road segments that have no road closure probability, an average speed of 30km/h is assigned for freeways and main arterials, and 25km/h is assigned for other road classes. The road closure probabilities are provided in three categories which are fully closed, 50 % closed and open with 3.5 m, for three seismic scenarios, which are occurrence probabilities of 100 years, 475 years and 950 years. This leads to consideration of nine scenarios for road closure probabilities. The mean value of probabilities obtained from nine scenarios are computed and then classified into 4 categories based on the histogram of the obtained probability values which are which are; “<=1%”, “1%-5%”, “5%-10%” and “>=10%” and then used in calibration of the costs.

For the road segments that have “<=1%” road closure probability, transportation network costs are decreased by 25%. For the road segments that have “1%-5%” road closure probability, transportation network costs are decreased by 50%. For the road segments that have “5%-10%” road closure probability, transportation network costs are decreased by 75%. Finally for the road segments that have “>=10%” road closure probability, transportation network costs are decreased by 100% which means the road segment is closed (Fig. 5.7).

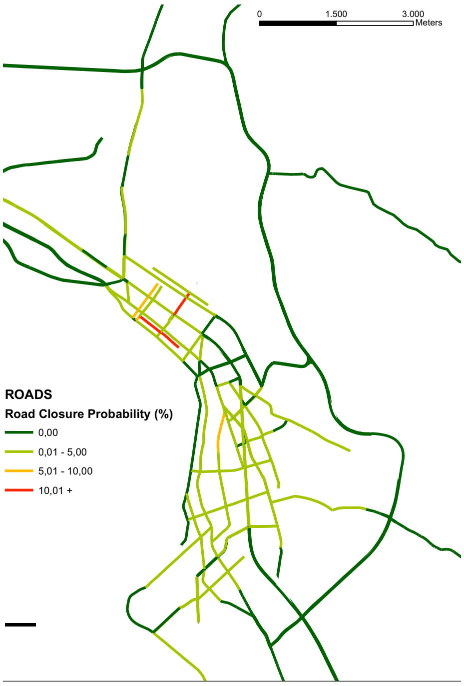


Fig. 5.7 Road closure probability for Thessaloniki main road network

In the accessibility modelling and visualization step, the health and shelter service accessibility scores are calculated by using the transportation network based travelling costs. Using the approach described in Section 5.3, health service accessibility measures of Thessaloniki are modelled in a GIS environment by using isochronal and zone based techniques (Fig. 5.8).

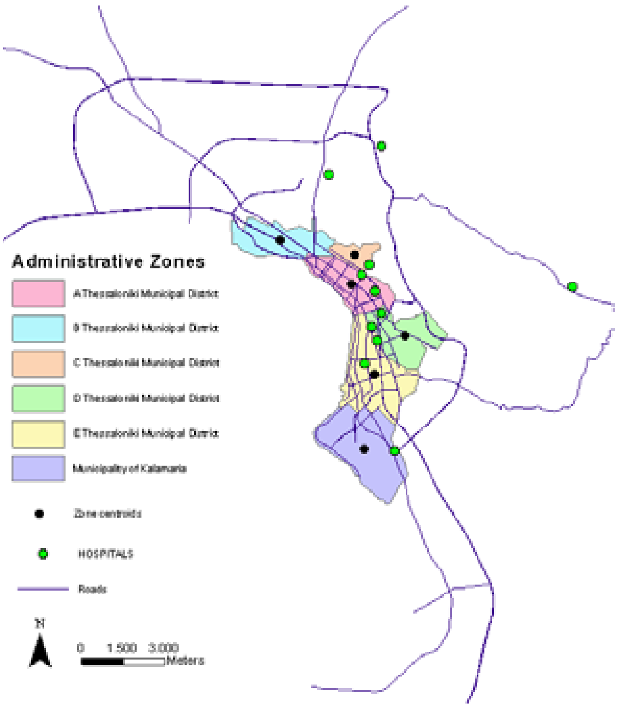


Fig. 5.8 The data of the transportation network, hospital locations and administrative zone centroids of Thessaloniki case study

Examples of the obtained results based on using different techniques (i.e., isochronal, gravity measure and travel time in zone-based technique) are presented below:

1. *Health service accessibility as a travel time measure in isochronal technique (*Fig. 5.9*)*

In this technique the 5, 10, 15 and 20 minute of catchment/service area boundaries are calculated starting from the health services. If 10 minutes cost is accepted as a critical time threshold for the health service accessibility, it can be observed that there are some over 10 minutes' accessibility regions in the west and south east part of the study area.

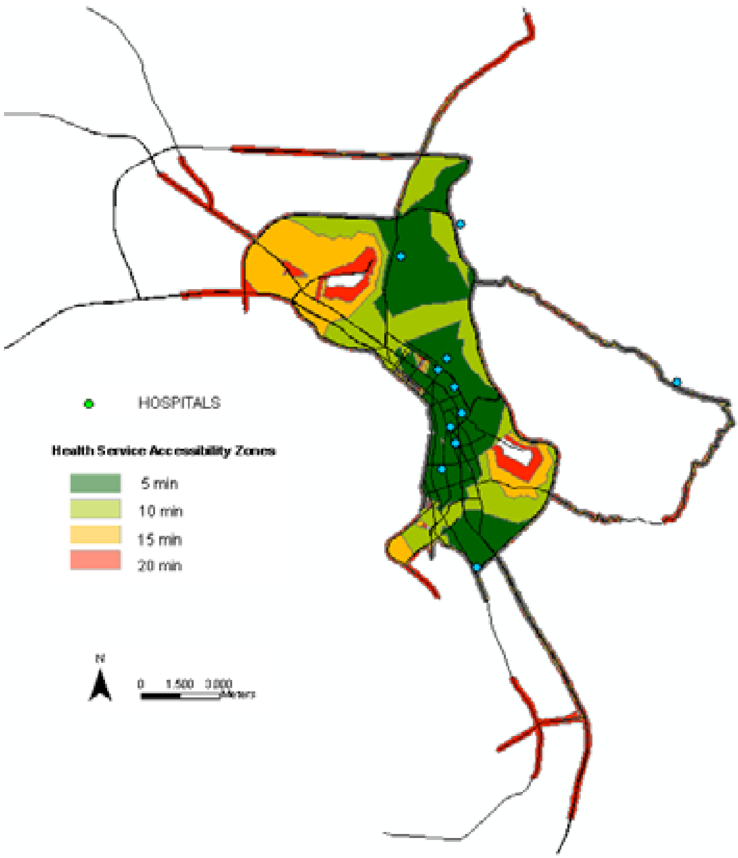


Fig. 5.9 Health Service Accessibility in Isochronal technique

2. *Health service accessibility as a travel time measure in zone based technique (Fig. 5.10)*

In this technique the cumulative time cost is calculated from each district to all hospitals. For the calculation of accessibility scores, the following formula is used:

$$A_i = \sum_{(j)} \frac{1}{\text{distance}_{(i\,j)\,(\text{origin to destination})}} \tag{5.1}$$

where "i" is the origin "j" is the destination. The calculated accessibility scores are normalized between 1 and 100. According to the results the "A Thessaloniki Municipal District" has the highest accessibility score and the "Municipality of Kalamaria" has the lowest accessibility score. It must also be pointed out that the "C Thessaloniki Municipal District" has no accessibility with the current road network conditions.

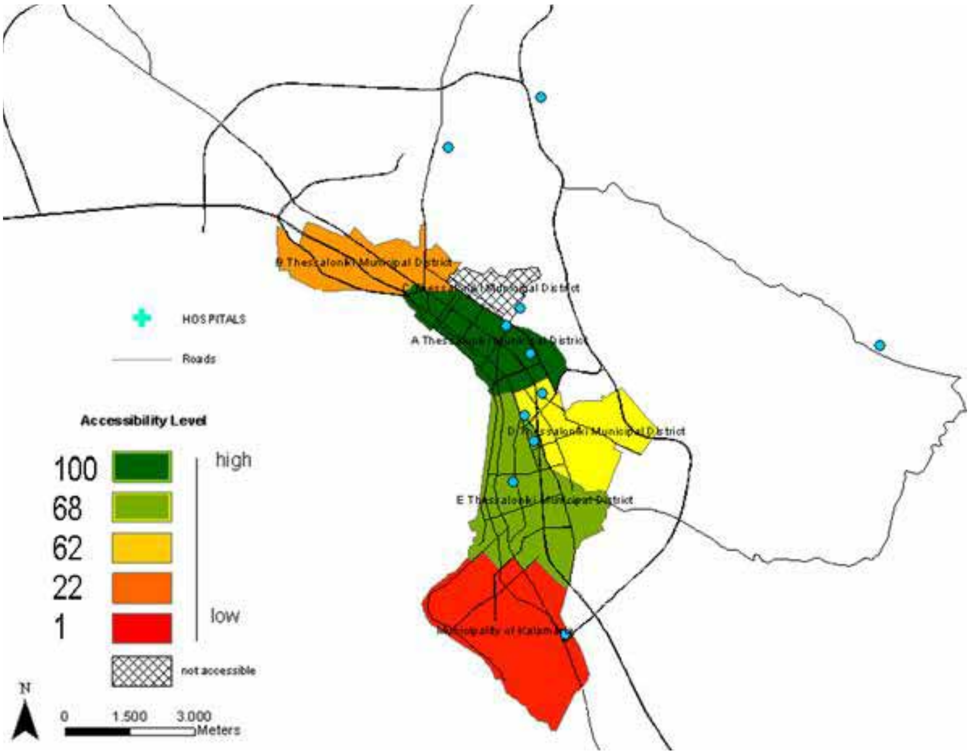


Fig. 5.10 Health service accessibility as a travel time measure in zone based technique

3. *Health service accessibility as a gravity measure in zone based technique (Fig. 5.11)*

In this technique the cumulative time cost is calculated from each district to all hospitals by considering the attraction/gravity factor of the hospitals. The calculation of accessibility scores, is based on the following formula:

$$\mathbf{A}_{i} = \sum_{(j)} \frac{\mathbf{G}_{(j)}}{\mathbf{distance}^{(i\,j)}_{(\text{origin to destination})}} \qquad (5.2)$$

where "i" is the origin "j" is the destination and G is the attraction factor of the supply which is calculated from the global value scores of the hospitals. The calculated accessibility scores are normalized between 1 and 100. According to the results the "A Thessaloniki Municipal District" has the highest accessibility score and the "Municipality of Kalamaria" has the lowest accessibility score. Although the gravity measure results seems similar to travel time measure results, the overall accessibility scores are lower in the gravity measures when compared with the travel time measures. Again "C Thessaloniki Municipal District" has no accessibility with the current road network conditions.

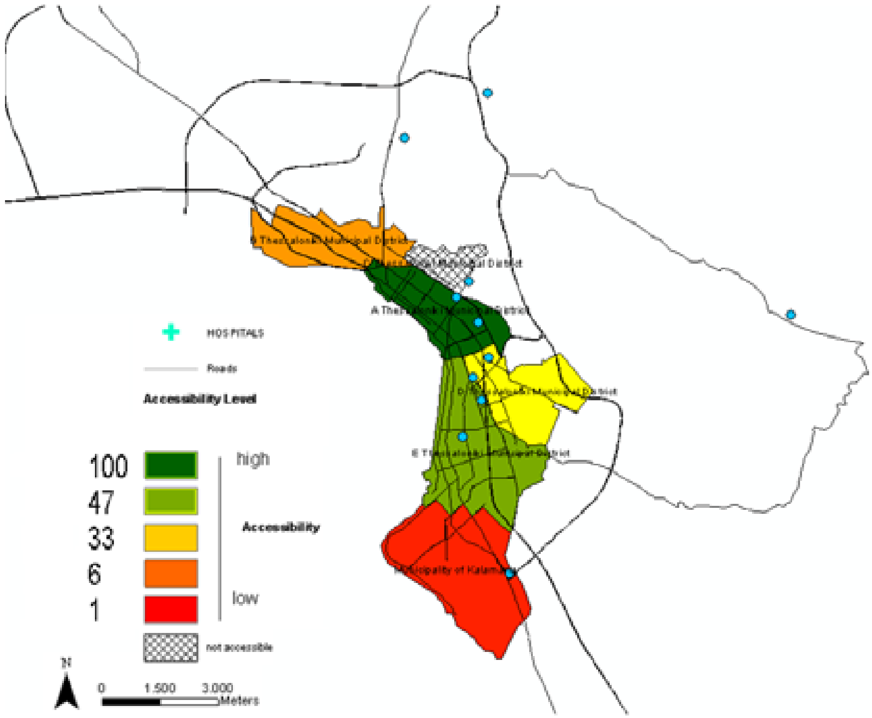


Fig. 5.11 Health service accessibility as a gravity measure in zone based technique

In GIS environment, it is also possible to define shortest routes between supply and demand points as in Fig. 5.12 and catchment area overlaps as in Fig. 5.13. The results are useful in terms of determination of the shortest route segments and required time cost in that segment by considering the costs in the transportation network.

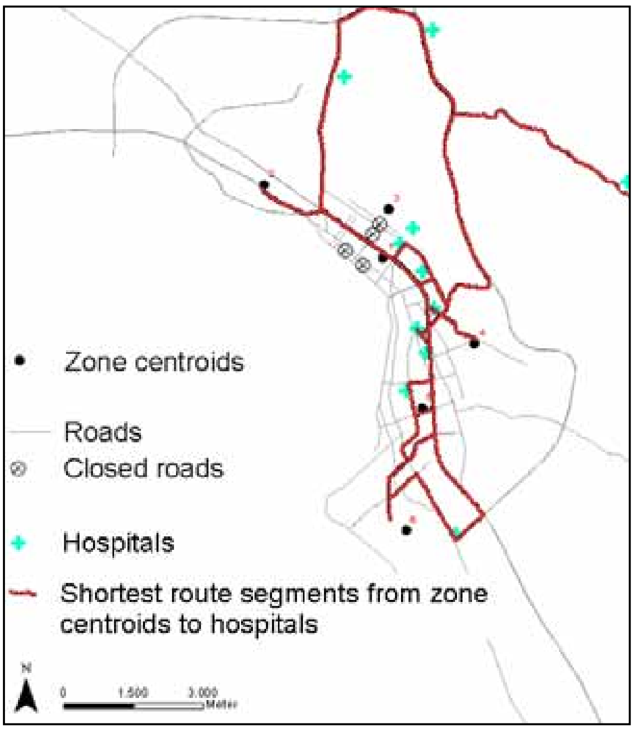


Fig. 5.12 Shortest routes from each of the health services to district centroids

In catchment area overlap analysis, it is possible to determine the locations that have accessibility advantages in terms of being in the catchment area of more than one hospital. For example when the 5 minutes accessibility catchment areas are analyzed, it can be observed that while the red zones on the boundaries are only inside 1 hospital catchment area, the green zones are inside more than 3 hospital catchment zones. The results are useful in terms of determination of the accessibility inequalities by considering the costs in the transportation network.

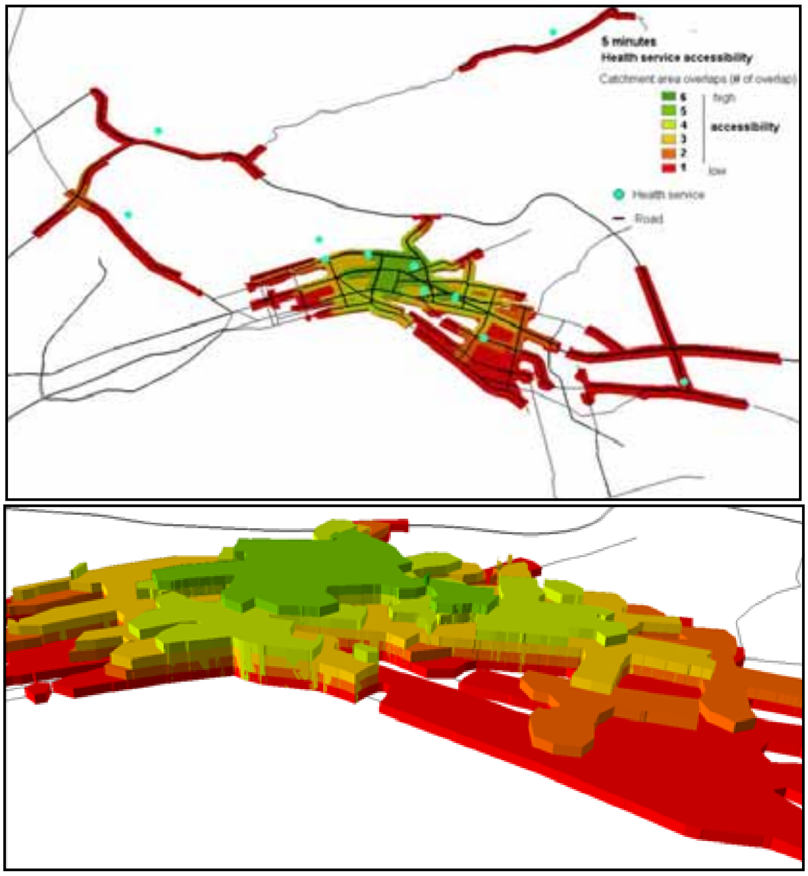


Fig. 5.13 Catchment area overlaps for health services

In conclusion, it should be noted that the application to Thessaloniki is performed to illustrate the methodology. It is a representative example, without considering the whole city and road network. Nevertheless, it can be shown that GIS based accessibility modelling can be an important guide for disaster managers to decrease the amount of disaster affected population, before, during and after disaster. As the amount of available resources are limited and disaster managers always have to decide the optimal location and capacity of available resources in the territory by considering location and capacity of demand locations, GIS based accessibility modelling can directly provide a vital support in terms of accessibility, location/allocation and service/catchment related issues. For example; GIS based accessibility modelling can directly help determination of location and capacity of mobile hospitals, search-and-rescue (SAR) teams, equipment storage depots, temporal living depots etc.

6 Shelter model

6.1 INTRODUCTION AND BACKGROUND

6.1.1 Introduction

For the planning of public shelter provisions in the aftermath of earthquakes the expected number of homeless persons and people seeking public shelter is an essential input for emergency managers. Few models exist that estimate the displaced or homeless population and the number of displaced persons seeking public shelter in an earthquake. Most Earthquake Loss Estimation software providing input for shelter needs are based on the HAZUS methodology which computes both displaced persons and shelter demand as a linear consequence of building damage. For example 90 percent of all occupants in severely damaged multi-family homes and 100 percent of all occupants in extensively and completely damaged multi-family and single-family homes are assumed to be displaced according to the HAZUS model default conditions (FEMA, 2003).

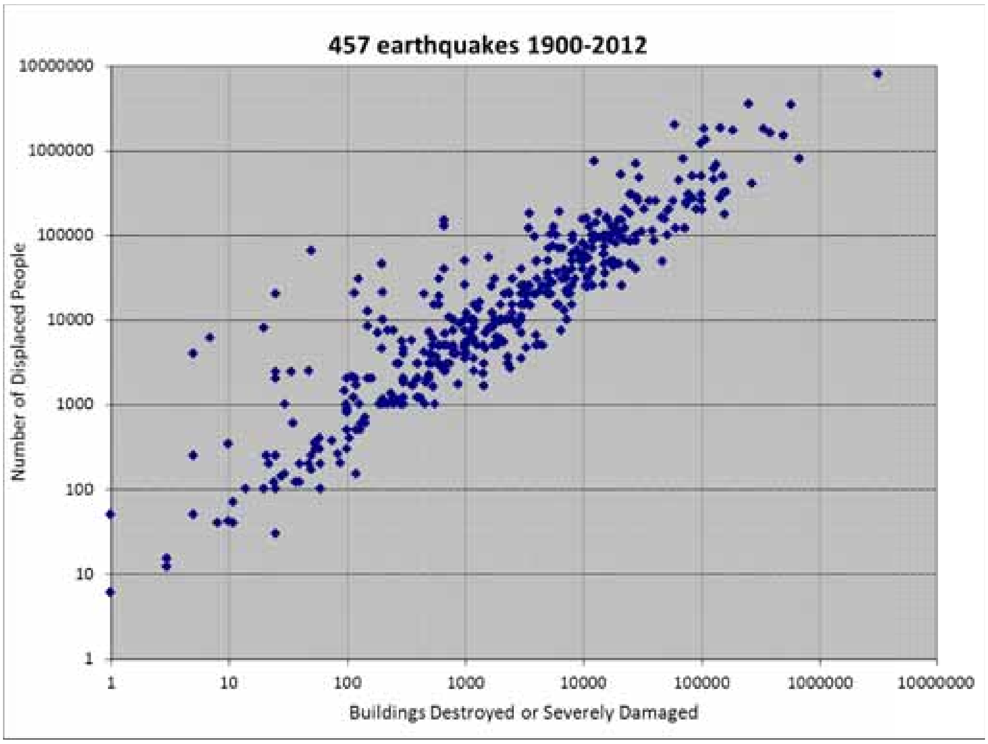
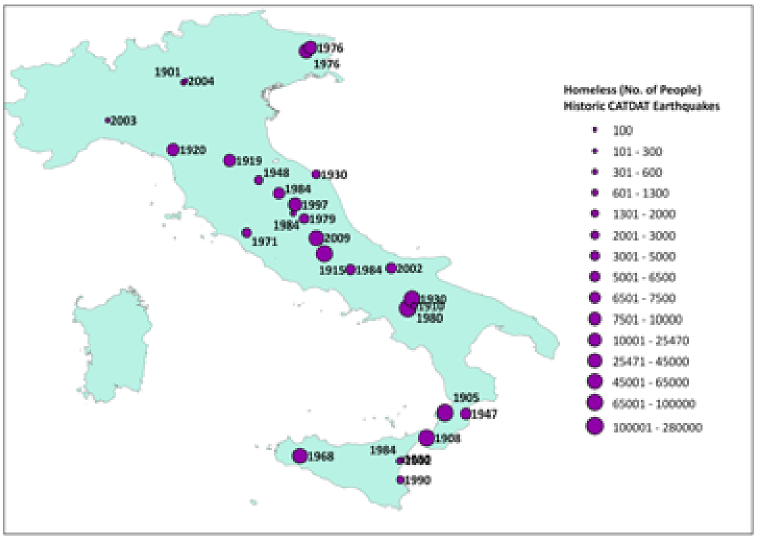


Fig. 6.1 Relationship between severely damaged and destroyed buildings and displaced persons after earthquakes (n = 457 earthquakes from 1900-2012)

Looking at data from 457 historic earthquakes from 1900-2012 with destroyed or heavily damaged building data in the CATDAT Damaging Earthquakes Database (Daniell 2003-2012, Daniell et al., 2011), a linear trend (on a logarithmic scale) of displacement and building damage can indeed be observed (Fig. 6.1). This data shows that the number of displaced persons is generally a little less than one order of magnitude larger than the number of destroyed or severely damaged buildings. However, the data in Fig. 6.1 also shows that in many past events the number of displaced persons is much larger than can be accounted for only through the number of occupants in severely damaged or collapsed buildings. Observations from past earthquake events found in the literature show that the number of displaced persons after an earthquake not only depend on external factors like building damage, loss of utilities, and weather conditions but also from household internal socioeconomic and individual factors such as safety concerns or fear of aftershocks (see full literature review of factors influencing displacement in Khazai et al., 2011a). The intention to leave can also be undermined through feasibility restraints, e.g. if the next shelter is too far away, if people are disabled or lack mobility. Even if households decide to leave their homes the final question is where they will find accommodation. Alternatives to public shelter are for example to stay with friend and family or in hotels. Thus, only a subset of the total population should be considered in computing demand for public shelter.



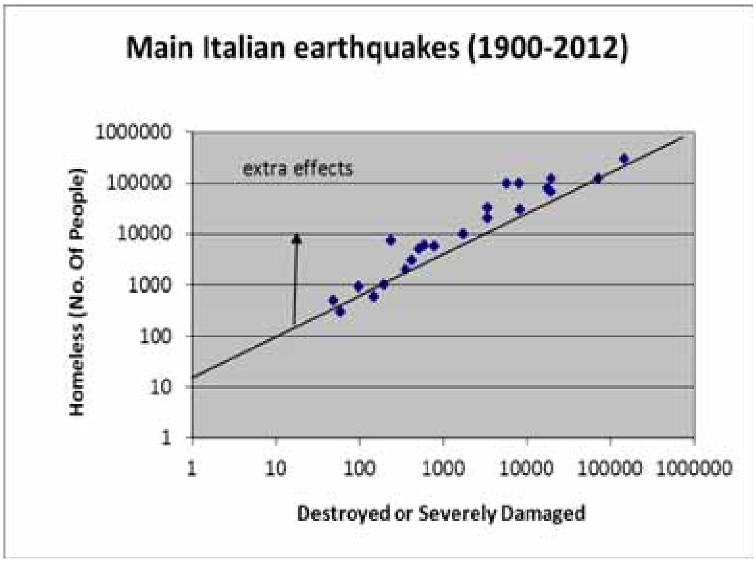


Fig. 6.2 Relationship between displaced populations and number of damaged buildings in main Italian earthquakes (n = 29 earthquakes from 1900 – 2012).

Fig. 6.2 shows displaced persons vs. building damage data for major Italian events from 1900 – 2012. As in Fig. 6.1 it can be observed that generally the number of homeless persons is about one order of magnitude larger than the number of severely damaged or destroyed buildings. For many of the events, however, some extra effects can be observed which can be attributed to environmental or socio-economic conditions influencing the displacement behaviour. For example, the Friuli earthquake in May 1976 created large-scale devastations, but there was no mass flight from Friuli. Several hundred tremors, aftershocks and the heavy rain that set in immediately after the quake destroyed the already badly damaged buildings and overwhelmed the resistance of the mountain population. When in September of the same year, another strong earthquake struck the Friuli area just before a strong winter set in the psychological effects were much worse on the population and a great exodus from the afflicted area began and many people evacuated to the Adriatic Coast (Geipel 1982). Without the heavy rainfalls after the first quake and the upcoming winter, the number of homeless people would have been substantially lower and closer to the proportion expected from damaged buildings.

6.1.2 Background

Few models exist that estimate the number of persons seeking public shelter in an earthquake. Most Earthquake Loss Estimation software providing input for shelter needs are based on the HAZUS methodology (Harrald and Al-Hajj, 1992; ABAG 2000), which calculates displaced populations as a function of structural damage to buildings. The HAZUS methodology uses a multi-attribute utility model which considers age, ownership, ethnicity and income as major factors contributing to demand for public shelters. The parameters for this model were originally developed by the American Red Cross and were based on expert opinion along with historical data (Harrald et al. 1992). Data from over 200 victims of the 1994 Northridge earthquake were analysed and used in finalizing these parameters. Below is a list of variables used by HAZUS for the calculation of shelter seeking population factor and the weights given to each indicator. For comparison the values used based on a survey of evacuation and shelter after the 1999 Chi Chi earthquake in Taiwan by Chien et al (2002) is also shown in Table 6.1.

MAEViz adapts and extends the HAZUS methodology for shelter demand by taking into account shelter needs arising from the loss of water and/or electric power (Elnashai, 2009). In MAEViz the shelter-seeking population is a subset of the “at risk” population and is calculated according to the following criteria:

- “At risk” population at day 1: HAZUS estimates for displaced people
- “At risk” population at day 3: HAZUS estimates for displaced people plus those without water and/or electric power at day 3
- Shelter-seeking population at day 1: HAZUS estimates for short-term shelter-seeking population
- Shelter-seeking population at day 3: “At risk” population at day 3 multiplied by a factor for the shelter-seeking population (this factor is calculated at the census tract level and is equal to the factor employed in HAZUS)

Both HAZUS and MAEViz calculate shelter demand as a linear consequence of building damage state. New approaches have recently been developed which simulate households' decision-making and consider socio-economic, temporal and spatial factors in addition to housing damage and lifeline loss to estimate displaced and shelter seeking populations (Chang et al., 2009; Wright and Johnston, 2010).

Table 6.1 Default weights used for socio-economic variables in Shelter Models

Subject	Indicator	HAZUS Default Weights	Haz-Taiwan Weights
Age	Population under 16	0.40	0.22
	Population between 16 and 65	0.40	0.18
	Population above the age of 65	0.40	0.24
Income	Family annual income < IM1	0.62	0.17
	IM1 < Family annual income < IM2	0.42	0.22
	IM2 < Family annual income < IM3	0.29	0.27
	IM3 < Family annual income < IM4	0.22	0.25
	Family income > IM5	0.13	0.25
Home Ownership	Self-owned Domicile	0.40	0.22
	Rented Domicile	0.40	0.16
Ethnicity	White	0.24	NA
	Black	0.48	NA
	Hispanic	0.47	NA
	Asia	0.26	NA
	Native American	0.26	NA

For example, the model by Chang et al. (2009) adopts an agent-based approach that utilizes census microdata on households and simulates households' decision-making about post-earthquake shelter on the basis of their dwelling condition, risk perception, mobility, and resources. These models have been developed for the North American, European and New Zealand contexts and implemented in cities such as Los Angeles and Wellington.

The model presented in SYNER-G will model populations at risk of being displaced as a function of building habitability, rather than building damage. Building habitability is derived based on empirical information which correlates building damage to building usability. It combines building usability, utility loss, and weather conditions to derive a ratio of populations in non-habitable buildings to determine the number of displaced persons.

The uncertainty with estimating populations seeking public shelter is much greater. Rather than estimating an absolute value of shelter-seeking populations, the approach in SYNER-G is to provide a multi-criteria framework where relative indices of shelter needs for each administrative district can be generated. This is explained in the Shelter Seeking Decision Model in Section 6.2.2, which provides the basis of an interactive decision-making platform that computes shelter needs based on criteria which is judged by the user to be the driving process in creating dislocation and desirability to seek public shelter. As these factors change from place to place, and there is no empirical data, to substantially validate them, having the multi-criteria interactive input for determining the end result is judged to be a more useful form than absolute values which the user has to accept on trust.

6.2 SHELTER DEMAND MODEL

Poor linkages between damage to physical systems and resultant social consequences remain a significant limitation with existing hazard loss estimation models (Bostrom et al, 2008). Most Earthquake Loss Estimation software providing input for shelter needs are based on the HAZUS methodology where the displaced population (determined only from building damage) is multiplied by a factor that considers age, ownership, ethnicity and income to determine demand for public shelters. These four parameters were originally developed by the American Red Cross and were based on expert opinion along with historical data from the 1994 Northridge earthquake (Harrald et al. 1992). New approaches have recently been developed which simulates households' decision-making in seeking shelter and considers socio-economic, temporal and spatial factors in addition to housing damage and lifeline loss to estimate displaced and shelter seeking populations (Chang et al., 2009; Wright and Johnston, 2010, Khazai et al., 2011). For example, the model by Chang et al. (2009) adopts an agent-based approach that utilizes census microdata on households and simulates households' decision-making about post-earthquake shelter on the basis of their dwelling condition, risk perception, mobility, and resources.

A new approach is presented for modelling emergency shelter demand by integrating shelter-seeking logic models into a systemic seismic vulnerability analysis and earthquake loss estimation software tool. The selection of socio-economic vulnerability indicators and other factors in the shelter logic model are based on an in-depth literature survey of historic earthquakes and are derived and validated using statistical models. Thus a new advancement to shelter estimation methodology is being explored through three types of key inputs: (1) the "habitability" of buildings which combines inputs from the physical models (building usability, utility loss and climate factors) to provide information on the habitability of a building and can be used as a better determinant in influencing the decision to evacuate than building damage alone; (2) GIS-based shelter accessibility analysis as an input to the shelter seeking model – not discussed in this report ; and (3) a multi-criteria decision model for implementing a shelter-seeking logic model based on complex socio-economic factors which ultimately lead to the decision to evacuate and seek public shelter. These three inputs are combined into a dynamic shelter model and software tool developed within the MAEViz platform to provide stakeholders an interactive framework in decision-making process for shelter planning and preparedness as well as resource allocation.

6.2.1 Building habitability

The first step in the decision to evacuate after an earthquake is based on the structural stability of a building and functional lifeline structures, such as access to water gas and electric power services. Weather conditions can further aggravate potential displacement from damaged buildings with disrupted lifeline services. If a building is only slightly damaged and it is very cold and there are no possibilities to heat, that home will be uninhabitable. During other seasons and weather conditions the same building might be habitable. In a rare study surveying post-earthquake survivors about their shelter preferences, Chien et al. 2002 found evidence that under normal weather conditions 67% of the interviewees after the 1999 Chi-Chi Earthquake chose to stay in nearby open fields or make a tent, whereas under wet or cold weather conditions only 17% showed a preference of staying there. Likewise cold weather played a major role in the choices of occupants sought shelter in both of the last two major earthquakes: 2011 Tohoku earthquake (Khazai et al., 2011; Daniell et al., 2011) and the 2012 Van earthquake in Turkey (Wenzel et al., 2012). As shown in Fig. 6.3 the "displaced persons" model provides an estimate of proportion of persons in habitable and uninhabitable buildings using the following inputs:

- Building Usability (building structural damage which leaves the building unusable, partially usable or fully usable depending on the level of damage and possibility of repairs)
- Utility Loss in each system (water supply, electric power, and gas) defined as one minus the ratio of satisfied to required demand
- Weather conditions (which determine the tolerance to utility loss)

The computed number of uninhabitable buildings is sensitive to a defined **tolerance threshold** for utility loss and **importance weights** given for each utility system in determining the total utility loss for each building. A set of default values have been provided for these, however due to the subjective nature of perceptions users may want to change these weights. Thus at the level of "building habitability" changes to t subjective user-defined parameters will affect the total output results. Enabling a dynamic interface where decision makers can interact with the proposed "Shelter Needs" module within the SYNER-G software is envisioned.

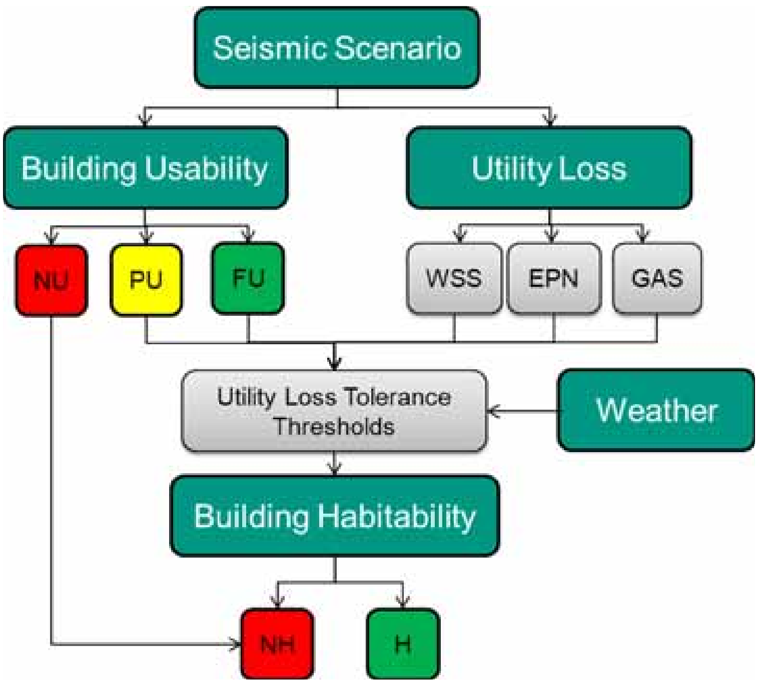


Fig. 6.3 Modelling of Building Habitability in SYNER-G

Building habitability is determined as a combination of the functionality of buildings (building usability), utility services and impending weather conditions and constitutes the first decision step in leaving or staying at home after an earthquake. Building *usability* is derived from a simplified semi-empirical approach as a function of severity of observed damage to structural and non-structural elements of buildings. The usability model was developed based on a detailed survey of 305 buildings in the densely packed suburb of Pettino obtained from the Italian Department of Civil Protection after the 2009 L'Aquila earthquake. The six usability classes considered during the survey were reduced in this model to just three: buildings which are immediately *non-usable* (*NU*), *partially usable* (*PU*) or *fully usable* (*FU*). Using the Pettino database, Usability Ratios (UR) for buildings were derived for each of the three usability classes as a function of the damage data, reported according to six damage states DS0 to DS5, which were also reduced to three damage states (none, yield, collapse). Usability ratios can be used then to estimate the number of persons in each of the three building usability classes (N_{FU}, N_{PU}, N_{NU}). Using the Usability Ratios in Table 6.2, the number of persons in each of the three building usability classes can be obtained using the following expression given in Eq. 6.1:

$$N_{FU\ or\ PU\ or\ NU} = \sum_{i=1}^{3} N_i NO_i UR_{i,FU\ or\ PU\ or\ NU} \tag{6.1}$$

where:

- i = damage level (i = 1, …, 3)
- N_i = number of buildings having damage level i,
- NO_i = number of occupants (at the time of the event) in each building for each damage level i,
- UR_i = usability ratio (UR) for damage level i for each usability class

Table 6.2 Empirically-derived Usability Ratios

UR	Damage state		
	None	Yield	Collapse
FU	0.87	0.22	0.00
PU	0.13	0.25	0.02
NU	0.00	0.53	0.98

To determine building *habitability* the usability of buildings is considered together with utility loss in a systemic seismic vulnerability analysis (Calvalieri et al., 2012). Non-usable buildings (*NU*) are also non-habitable. If a building is fully or partially usable, depending on the level of residual service in the utilities and the prevailing weather conditions at the time of impact, it can be habitable (*H*) or non-habitable (*NH*). For each utility, the level of residual service is satisfactory when the Utility Loss (UL), defined as one minus the ratio of satisfied to required demand, is lower than a threshold value ($UL_i < UL_{Ti}$). The threshold values depend on Weather conditions and Building Usability and due to the subjective nature of perceptions, the Utility Loss Threshold (UL_{Ti}) should be established on a context-specific basis by the analyst. The total Utility Loss is a weighted average of UL_i on each of the utilities, with weights w_i provided by the analyst, as given by Eq. 6.2:

$$UL = \sum_{j=1}^{N_{UN}} UL_j w_j \tag{6.2}$$

where:

- j = utility systems (j = 1, …N_{UN} with N_{UN} = 2 in this application)
- UL_j = Utility Loss in system j

- w_j = weight associated with the importance of loss in utility system j in making the building uninhabitable

The percent of fully or partially usable buildings that are non-habitable (NH_{FU} or NH_{PU}) is thus determined as the portion of buildings which have utility losses greater than the utility loss threshold value ($UL \geq UL_T$). The Uninhabitable Building Index (UBI) is computed as the ratio of occupants of buildings that are uninhabitable to the total population (N) according to the following relationship, given in Eq. 6.3:

$$BHI = \frac{N_{FU}NH_{FU} + N_{PU}NH_{PU} + N_{NU} - N_d}{N} \tag{6.3}$$

where:

- N_{FU} = number of occupants in buildings that are fully usable
- N_{PU} = number of occupants in buildings that are partially usable
- N_{NU} = number of occupants in buildings that are non-usable
- NH_{FU} = percent fully usable buildings that are non-habitable, where UL ≥ ULT
- NH_{PU} = percent partially usable buildings that are non-habitable, where UL ≥ ULT
- N_d = number of dead persons estimated in a selected casualty model

6.2.2 Shelter-seeking decision model

The basic elements of the logic model for the shelter demand model are based on the ideas of Chang et al. (2009). The shelter model combines each of the decision steps (represented as an output indicator) shown in Fig. 6.4 in a weighted multi-criteria decision analysis framework according to the following scheme: D1 is given by an output indicator as the proportion of population residing in uninhabitable buildings criteria; D2 and D3 are a combination of a number of internal and external factors and given by an output indicator representing the desirability to evacuate criteria; D4 is given by an output indicator representing the desirability to seek public shelter based on the access to resources criteria.

Each step is answered by yes or no and leads either to the next decision step or is answering the final destination residents probably choose. Thus, all residents whose home is uninhabitable (D1) and who have no alternatives will seek public shelter. Also people who have a lower *resistance to evacuation* by either finding it more desirable to leave their home (D2), and/or are forced to leave their home (D3), will seek public shelter if they lack other alternatives (D4). Each of the decision steps are represented by one output indicator which are combined in a weighted multi-criteria decision analysis framework according to the following scheme.

- D1 is given by an output indicator as the proportion of population residing in ***uninhabitable buildings criteria***.
- D2 and D3 are a combination of a number of internal and external factors and given by an output indicator representing the ***desirability to evacuate criteria***.
- D4 is given by an output indicator representing the ***access to resources criteria***.

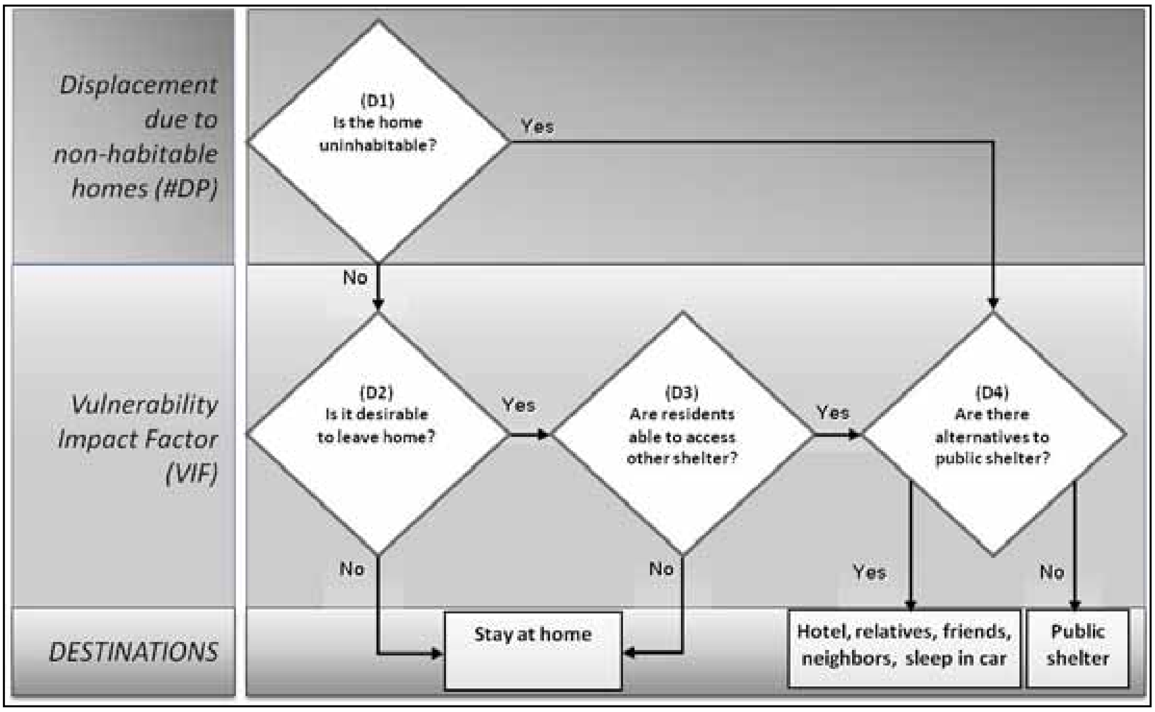


Fig. 6.4 Proposed model framework for the Shelter Seeking Population Index

The decision to evacuate one's home after an earthquake and to utilize public shelter is correlated with a variety of social and demographic factors (Tierney et al, 2001). These decisions are also usually made at the household level; however, as was seen in the case of the L'Aquila earthquake the decision to evacuate can also be imposed by government authorities that make an evacuation of homes mandatory. A survey of disaster literature regarding post-earthquake sheltering demand provided an initial basis for selection of relevant socio-economic indicators related to the desirability to evacuate (Khazai, et al., 2012; Braun, 2011). The main factors influencing evacuation behaviour were derived from 18 key studies and are shown in Fig. 6.5. Factors such as income, age and minority status received the most nominations; whereas factors such as race and ethnicity have been dissected thoroughly by US researchers, these were considered as one factor "belonging to the minority" within this model. Other factors such as proficiency of English language - one of the indicators of the Social Vulnerability Index (SoVI) (Cutter, 2008) - also apply to the particular context of the United States or other primarily English speaking countries and were not adopted in this model.

While the literature survey provides for a comprehensive wish list of indicators, an important requirement for operationalizing the approach is that it should be possible to quantitatively populate the socio-economic indicators based on an approach that can be harmonized at the European level for the urban scale of analysis. As such, data was compiled from the EUROSTAT Urban Audit for European cities at the sub-city districts (SCD) level and used as a next step to pre-select the most relevant indicators from the Urban Audit that were found in the literature survey. In order to narrow down the selection of the most influential indicators from the Urban Audit and to assign a set of default weights a factor analysis was conducted with the Urban Audit data. Out of the 338 indicators described in the Urban Audit, data is available for only 44 indicators at the SCD level. The 44 indicators were analyzed for two periods: 1999-2002 (7856 districts in 321 cities in 30 European countries); and 2003-2006 (2972 districts in 173 cities in 24 European Countries). Principal component analysis (PCA) was used to calculate the inter-correlation between variables and a new set of transformed variables was created where the importance of each of the new variables in terms of the variability of the data is identified. It was found that close to 75 percent of variation in data is represented by 8 dimensions shown in Table 6.3 (see Chapter 4 and Vangelsten et al., 2011 for detailed report). Additionally, the PCA provides a possibility to model the relative influence of each data in terms of their explanatory power (i.e., how much of the statistical variation can be explained by each indicator).

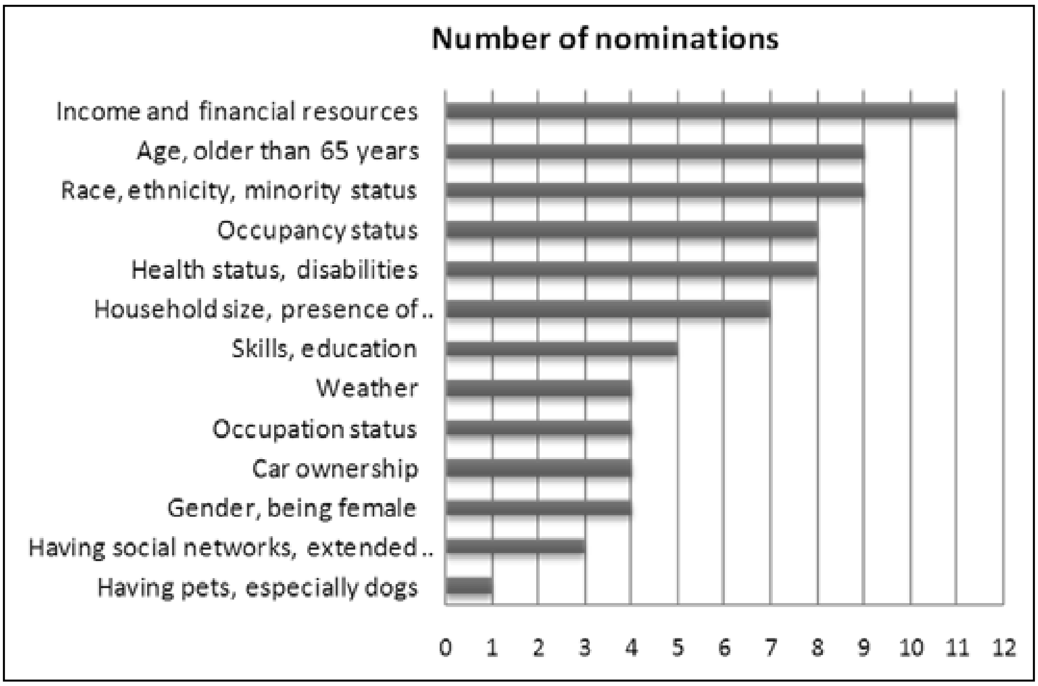


Fig. 6.5 Number of nominations found for indicators in the 18 studies surveyed.

Table 6.3 Results of Principle Component Analysis of Urban Audit Data

No	Subjective Factors	Strongest correlated indicator	Strongest correlation value
1	Mortality/Age	Mortality rate for <65 per year	-0.88
2	Education	Prop. of working age population qualified at level 3 or 4 ISCED	+0.77
3	Lone Parent with Children	Prop. of households that are lone-parent households	+0.68
4	Population Density	Population density: total resident pop. per square km	-0.64
5	Migration/Ethnicity	Proportion of Residents who are not EU Nationals and citizens of a country with a medium or low HDI	+0.58
6	Gender	Proportion of females to males in total population	+0.51
7	Unemployment	Unemployment rate	-0.54
8	Sub-standard Housing	Proportion of dwellings lacking basic amenities	+0.67

The literature survey and the statistical models provide a set of candidates for operationalizing the shelter-seeking decision model presented in Fig. 6.4. The first step (D1) is determined through the building habitability analysis as discussed above. The following presents the methodology and indicator framework related to desirability to evacuate (D2 and D3) and desirability to seek public shelter (D4).

Desirability to evacuate

The desirability to evacuate is a combination of factors related to a set of internal factors which is a reflection of perceived security and safety, as well as external factors forcing residents to leave. Feeling safe at home (or the feeling that it is safer to leave) is subjective and depends on a large range of factors each with different perceived importance values and cultural contexts. As mentioned above the perception of weather conditions is compound with the building damage and utility services disruptions. The resistance to evacuation is also influenced by sociological and economic factors, like having strong social networks, belonging to a minority or being disabled, having enough knowledge and financial resources to protect yourself, and knowing where to obtain information. Other factors influencing the perceived security are conditions such as fear and anxiety of aftershocks or mistrust in safety evaluation of home (green, yellow and red tags) which are more difficult to describe and define quantitatively through indicators. Thus, the desirability to leave is a combination of a complex set of social factors and is ultimately determined by the individual's perception of the importance of each one of these factors in driving the decision to evacuate. While desirability to leave represents an internal driver to evacuation, the resistance to evacuation is also driven by external decisions imposed on the affected population which in some cases may force them to evacuate (e.g., mandatory evacuation of the entire city center as in 2009 L'Aquila earthquake, or radiation advisory and evacuation radius as in the aftermath of the 2011 Tohoku earthquake and tsunami).

$$DE = EF \times \sum_{i=1}^{n} w_i \, I_i \tag{6.4}$$

- DE = Desirability to evacuate
- w_i = overall weight given to each indicator
- I_i = indicators representing the desirability to evacuate
- EF = External Factors, derived from a GIS analysis and/or different evacuation scenarios. el. Three evacuation scenarios are proposed for consideration in the analysis:
  - Full evacuation of urban core or city center (the geographical boundaries for the urban core of 337 European cities are available in GIS form from the Urban Audit)
  - Full evacuation of neighbourhoods with damage levels above user-defined thresholds
  - Full evacuation of geographic areas based on a user-defined evacuation area

Table 6.4 Urban Audit Indicators influencing Desirability to Evacuate

Decision Factors	Urban Audit Indicators for Desirability to Evacuate
Household Tenure (Owner vs. Renter)	-Prop. of households living in priv. rented housing -Proportion of households living in owned dwellings
Housing Type (Single, Multi-family)	-Number of houses per 100 apartments -Proportion of households living in social housing -Proportion of Dwellings lacking basic amenities -Proportion of non-conventional dwellings
Household Type (Large Families with Children, Single Parents)	-Avg. Size of households -Lone-parent households with children aged 18 or under -Proportion of households living in social housing
Age (Children and Elderly)	-Proportion of total population aged 0-4 -Proportion of total population aged 75 and over -Mortality rate for population aged 65 and under
Perceived Security of Neighborhood	-Total Number of Recorded Crime per 1000 population

Desirability to seek public shelter

Not all displaced population will seek public shelter, and some may find alternative shelter accommodations (rent motel rooms or apartments), stay with family and friends, or leave the affected area. For estimations of shelter demand it is necessary to account various factors that lead to populations seeking public shelter. Desirability to seek public shelter in this study is given by an indicator model related to the “Access to Resources” which accounts for both “push” factors (such as low income, lack of mobility or having no social networks) and “pull” factors (such as being too far from the shelter sites). The “push” factors are determined in terms of socio-economic drivers, while the “pull” factor is an input from a GIS-based shelter accessibility model (Khazai, et al., 2011b). The question of accessibility relates mostly to residents who are able to choose between different destinations. The proximity and ease of access of shelter locations might be key criteria for these households whose decision of leaving is not founded on aspects of vulnerability but on individual preferences. The Shelter Seeking Index (SSI) is then derived as an additive weighted sum of each of the indicators constituting the shelter seeking population and multiplied by how accessible each of the designated shelter sites are, according to:

$$SSI = AI \times \sum_{j=1}^{n} w_j \, I_j \tag{6.5}$$

where:

- SSI = Shelter Seeking Index
- w_i = overall weight given to each indicator
- I_i = indicators representing shelter seeking population
- AI = Accessibility Index, derived from a GIS distance-cost analysis to shelter sites

Table 6.5 Urban Audit Indicators influencing Desirability to Seek Public Shelter

Decision Factors	Urban Audit Indicators for Shelter Seeking Index
Income	-Percent of households with less than 60% of national median annual disposable income -Proportion of households reliant upon social security
Unemployment	-Unemployment rate
Migration/ Ethnicity	-Participation rate at national/city l elections -Number of residents born abroad (not only nationals) -Residents not EU Nationals and citizens of a country with a very high or high HDI -Residents who are not EU Nationals and citizens of a country with a medium or low HDI
Education	-Prop. of working age population qualified at level 1, 2, 3 4, 5 and 6 ISCED

6.3 MULTI-CRITERIA SHELTER MODEL

The integrated shelter needs model developed here is based on a multi-criteria decision theory (MCDA) framework which allows the bringing together of parameters influencing the physical inhabitability of buildings, with social vulnerability (and coping capacity) factors of the at-risk population to determine as well as external factors to determine the desirability to evacuate and seek public shelter. As shown in Fig. 6.6, the mutli-criteria framework can be described schematically as composed of the two main criteria: overall population at risk of being displaced after an earthquake (DPI) and the proportion of this population likely to seek public shelter (SSI). Subsequently, the total demand for public shelter for a particular location (i.e., city district) can be described as a product of the population at risk of being displaced (D1, D2 and D3) to the population likely to seek public shelter (D4). This can be expressed by Eq. 6.6:

$$SNI = DPI \times SSI \tag{6.6}$$

where, SSI is derived from a weighted index related to lack of access of resources indicators in a community or neighbourhood, and DPI is given as occupants in uninhabitable buildings amplified by external and internal factors related to desirability to evacuate according to Eq. 6.7

$$DPI = BHI\ (1 + DE) \tag{6.7}$$

The integrated shelter needs model developed here provides a multi-criteria framework which brings together the parameters influencing the physical inhabitability of their buildings, with coping capacities and social fragilities of the at-risk population to determine an index of total shelter need in different neighbourhoods of a city. The mutli-criteria framework can be described schematically in Fig. 6.7 as composed of the three measures, which will be described in detail here: a) Uninhabitable Building Index (UBI), b) Lack of Resistance to Evacuation (LRE) and c) Shelter Seeking Index (SSI).

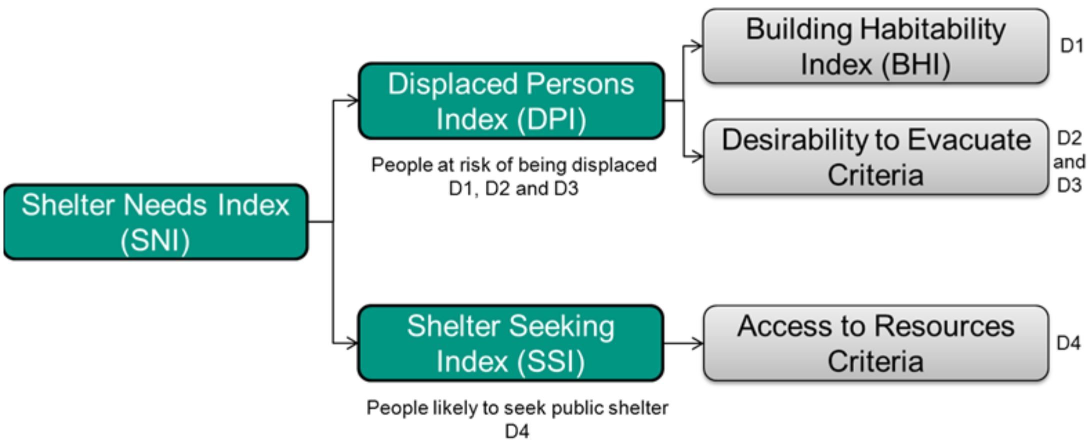


Fig. 6.6 Decision criteria for computing Shelter Needs Index (SNI)

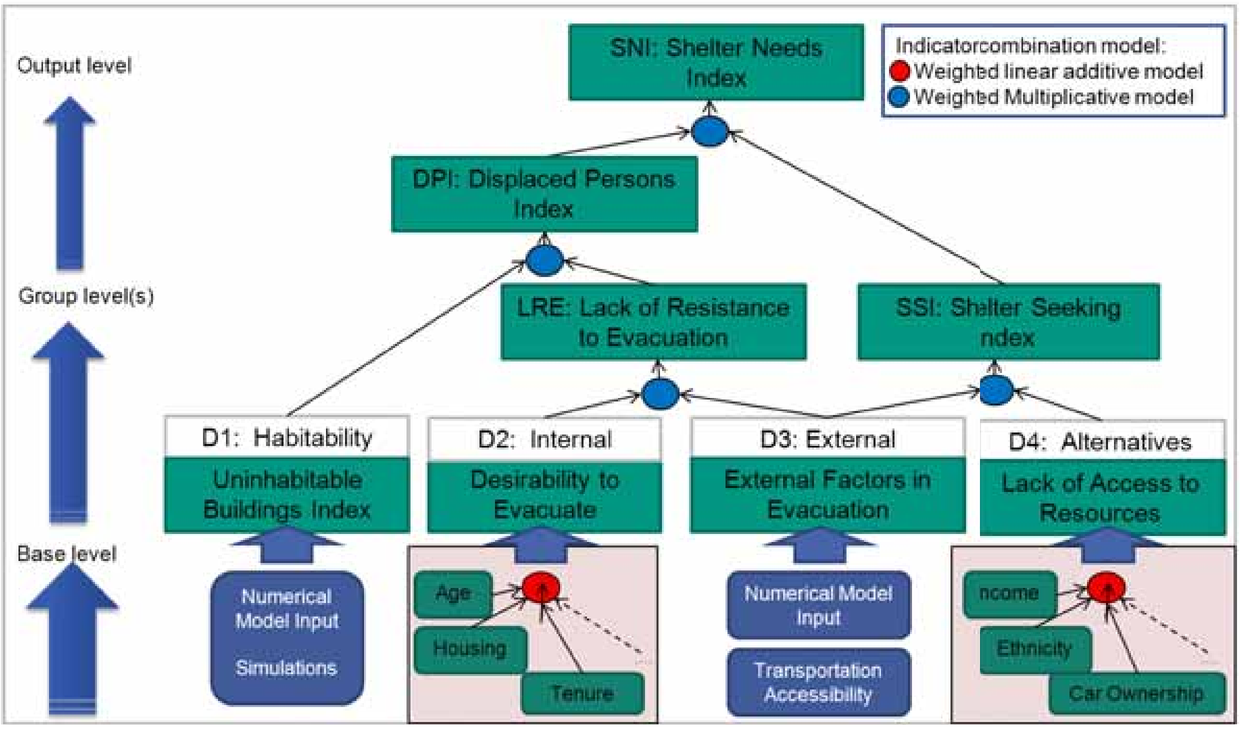


Fig. 6.7 Hierarchical multi-criteria framework to describe shelter needs

6.4 MODEL IMPLEMENTATION IN L'AQUILA

To demonstrate the shelter methodology it has been applied to the L'Aquila earthquake of April 6, 2009, where detailed data on post-earthquake *Building Usability* (AEDES Survey of 1667 buildings); *Socio-economic* data for 106 fractions (ISTAT data); and *Shelter Population* data from April to August 2009 for 107 shelter sites (Italian Civil Defense) were used to validate the model. An important note is that due to issues of confidentiality and data privacy the relevant data for the validation of the loss model, in particularly those related to the evacuation rate, casualty and injuries were made available only in aggregated form. Thus the unit of analysis was established in terms of the Mixed Operations Centers (COM). These centres had overall coordinating role in its own territory for all rescue operations with tasks that included hospitalization of the injured, demolition, food supply, public health and sanitation, shelter provision, repair and restoration of damaged infrastructure and emergency response. As such, the area struck by the L'Aquila earthquake was divided into eight COMs. The list below illustrates the eight COMs and the fractions that they respectively include. The location of shelter sites in each of the COMs is shown in Fig. 6.8 on top of the MMI intensities after the L'Aquila earthquake.

- COM 1 – L'Aquila (L'Aquila, Preturo, Sassa, San Vittorino, all the fractions not included in other COMs);
- COM 2 – S. Demetrio (Acciano, Barisciano, Fagnano alto, Fontecchio, Fossa, Poggio Picenze, Prata d'Ansidonia, S. Eusanio Forconese, San demetrio dei Vestini, San Pio delle Camere, Pione degli Abruzzi, Villa S. Angelo);
- COM 3 – Pizzoli (Arischia, Barete, Cagnano Amiterno, Campotosto, Capitignano, Lucoli, Montereale, Pizzoli, Scoppito, Tornimparte);
- COM 4 – Pianola (Aielli, Avezzano, Bagno, Bagno Grande, Celano, Civita di Bagno, Collarmele, Massa d'Alpe, Ocre, Ovindoli, Pianola, Rocca di Cambio, Rocca di Mezzo, Roio Colle, Roio Piano, Roio Poggio, S. Benedetto di Bagno, Valle Sindola di Bagno);
- COM 5 – Paganica (Aragno, Assergi, Bazzano, Camarda, Filetto, Paganica, Pesco Maggiore, Tempera, Onna, San Gregorio);
- COM 6 – Navelli (Brittoli, Bussi sul Tirino, Calascio, Capestrano, Caporciano, Carapelle Calvisio, Castelvecchio Calvisio, Castel del Monte, Civitella Casanova, Collepietro, Cugnoli, Montebello di Bertona, Navelli, Ofena, Popoli, S. Benedetto in Perillis, S. Stefano di Sessanio, Torre de' Passeri, Villa S. Lucia degli Abruzzi);
- COM 7 – Sulmona (Anversa degli Abruzzi, Bugnara, Cansano, Castel di Ieri, Castelvecchio Subequo, Cocullo, Corfinio, Gagliano Aterno, Goriano Sicoli, Introdacqua, Molina Aterno, Pettorano sul Gizio, Pacentro, Pratola Peligna, Prezza, Raiano, Roccacasale, Secinaro, Sulmona, Vittorito);
- COM 8 – Montorio al Vomano (Arsita, Castel Castagna, Castelli, Colledara, Cortino, Crognaleto, Fano Adriano, Isola del Gran Sasso, Montorio al Vomano, Pietracamela, Rocca S. Maria, Teramo, Torricella Sicura, Tossicia, Valle Castellana).

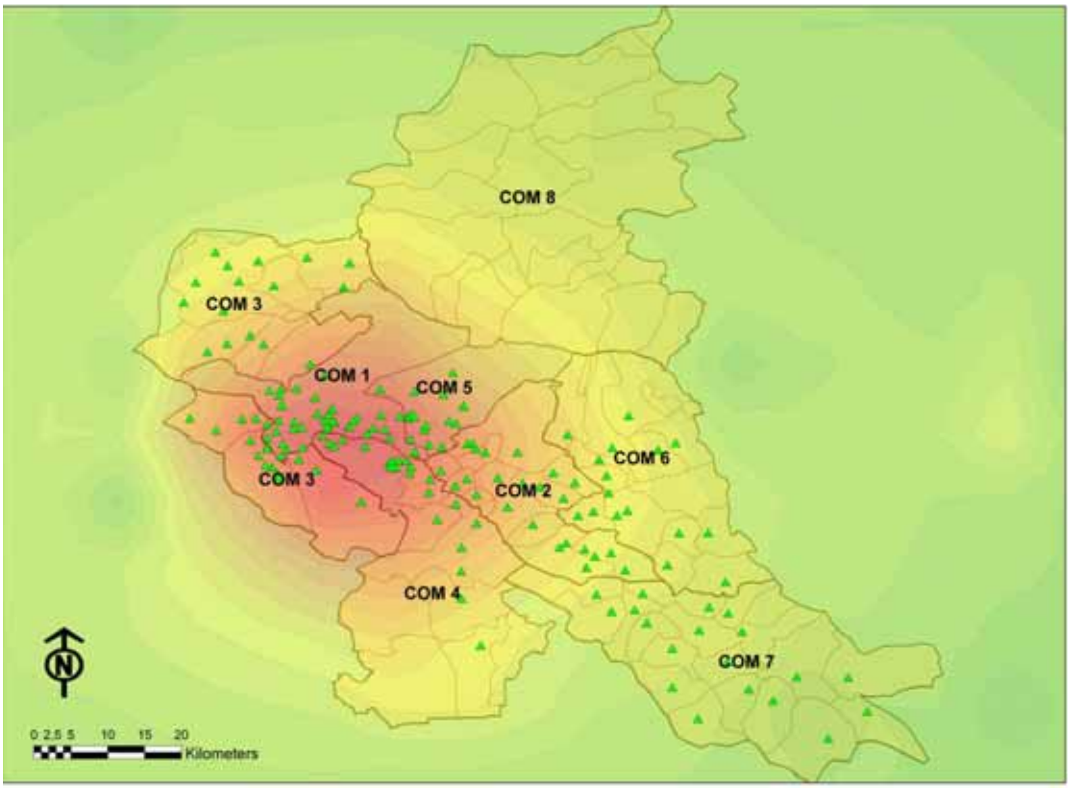


Fig. 6.8 Location of shelters in each of the COMs overlayed on MMI intensities after the L'Aquila earthquake

6.4.1 Socio-economic data

The source of the socio-economic data compiled for the regions affected by the L'Aquila earthquake is the Istituto Nazionale di Statistica (ISTAT) which deals with the Italian statistical system. In particular the data refer to the 14th General Census of Population and Housing (2001), and are related to socio-demographic characteristics of the resident population and the structural characteristics of housing and buildings. The territorial scale of the statistics available can be summarized as follows:

- Regional data (NUTS 2: population of the Abruzzo region = 1.262.392)
- Provincial data (NUTS 3: population of the L'Aquila province = 297.424)
- Municipality data (NUTS 4 and 5: population between 500 and 80.000)

The available indicators used for the analysis from the14th General Census of Population and Housing (2001), refer to the Abruzzo region (NUTS 2) and L'Aquila city (NUTS 3) (October 21, 2001) are shown in Appendix B. Since the data available for L'Aquila fractions are not comparable with the data available for municipalities of L'Aquila, Teramo and Pescara Provinces, the aggregated resident populations on fraction level have been used as a normalization parameter for each fraction. Similarly, the resident population of L'Aquila municipality has been used as normalization parameter for the combined data of all shelters and fractions within the L'Aquila municipality and was then compared to all other COMs not including L'Aquila municipality fractions. In a first analysis it was found that resident population within each COM alone could not account for total shelter population numbers. As can be seen in Fig. 6.9, there is significant deviance from resident population to shelter population, particularly in April in COM 5.

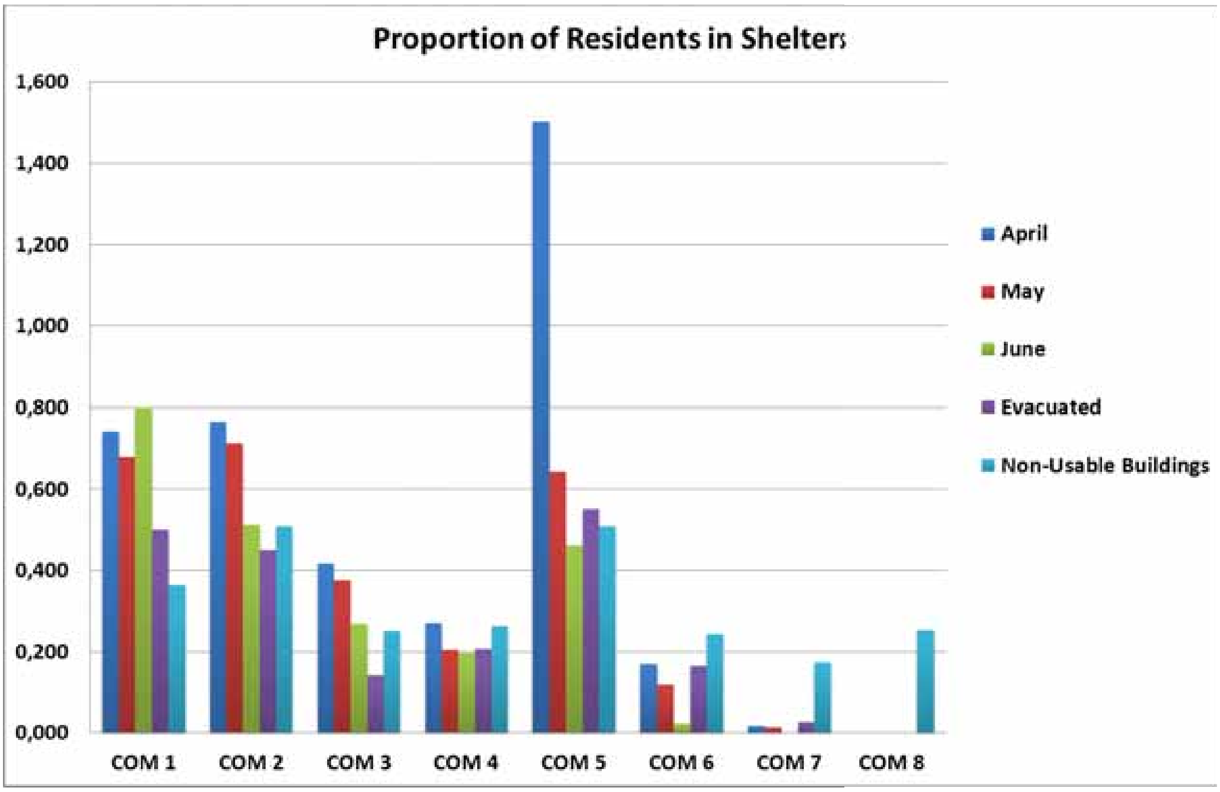


Fig. 6.9 Proportion of COM Residents in Shelters, Evacuated People and Non-Usable Buildings

To make up for the surplus in shelter population, migration between adjacent COMs must be considered. This also implies that normalization – though needed to compare data from different levels – provides biased results.

It has been possible to obtain the following data for each COM (All the collected and processed data are included in Deliverable 4.5):

1. Land area, population density, population, households, buildings and houses by municipality.
2. Resident population by age and municipality.
3. Resident population by marital status and municipality.
4. Resident population in the age of 6 years and over by level of education and municipality.
5. Resident population aged 15 and over by professional and non-professional status and municipality.
6. Employment by professional status and municipality.
7. Employment by economic activity and section of municipality.
8. Families by number of household members and municipality.

9. Households by type of unit and municipality.
10. Foreign resident population by geographical area of citizenship and municipality.
11. Residential buildings by period of construction and municipality.
12. Dwellings occupied by residents, occupants and rooms for tenure and municipality.
13. Dwellings occupied by residents, families and components for number of rooms and municipality.
14. Dwellings occupied by residents for types of services, and municipality area.

6.4.2 Building damage and usability data

The fruitful collaboration of AMRA with the Italian Department of Civil Protection and the National Research Council has allowed collecting data from the AeDES forms aggregated for the eight illustrated COMs. In particular for the benchmarking analysis the AeDES data listed below has been collected and processed. All the collected and processed data are included in Technical Report D4.5 (Iervolino, et al., 2012).

1. Total Number of buildings surveyed in the respective zone
2. Number of Stories (Section 2, AeDES)
3. Building Age (Section 2, AeDES)
4. Building Use (Section 2, AeDES)
5. Residential Building Units for units class (Section 2, AeDES)
6. Building Utilization (Section 2, AeDES)
7. Building Occupants (Section 2, AeDES)
8. Building Type (Section 3, AeDES)
9. Building Structural Damage: Vertical Structures; Infills and partitions (Section 4, AeDES)
10. Building Non-structural Damage (Section 5, AeDES)
11. Building damage induced by the collapse or fall of objects (Section 6, AeDES)
12. Soil and Foundation (Section 7, AeDES)
13. Building Usability (Section 8, AeDES)
14. Proposed Interventions (Section 8, AeDES) for each of the mentioned interventions
15. Evacuation of Buildings (total count) (Section 8, AeDES) and evacuation according to building usability class
16. Evacuation as a ratio of total occupants according to Building Usability Class (Section 2 and 8, AeDES)
17. Evacuation according to number of units (Section 2 and 8, AeDES)
18. Evacuation as a ratio of total occupants according to number of units (Section 2 and 8, AeDES)
19. Evacuation according to break of lifelines (Section 5 and 8, AeDES)

The Proportion of Non-Usable buildings deduced from AeDES data was also included in a first analysis. As shows Fig. 6.9, there appears to be no linear relationship between the proportions of Non-Usable buildings and people in shelters.

6.4.3 Data from public shelters

For each COM, AMRA have collected information about the number of shelter sites, the total number of shelters, the population in the shelters, the number of kitchens and the number of advanced medical posts (PMA, in Italian Postazioni Mediche Avanzate) updated to May 8, 2009. The table below shows the data for each COM. When shelter population evolution is compared between the different COMs as shown in Fig. 6.10, the results support the assumption that migration may have taken place between displaced populations of the different COMs. Most COMs observed a drop in shelter population after the first month. The most drastic development is observed in COM 5, where there is a drop of almost 60 percent in shelter population from April to May. Contrary is the development in COM 1 with an increase in people in shelter until end of June. This increase could partly account for the loss in COM 5.

Table 6.6 AMRA Shelter Data for all COMs (Resident Population via ISTAT data)[3]

	Total Number of Fractions	Fractions with Shelters	Total Number of Shelters	Resident Population
L'Aquila Municipality	42	35	63	68503
COM 1	27	21	37	15061
COM 2	12	12	24	8699
COM 3	9	9	33	14635
COM 4	15	11	23	17696
COM 5	9	9	18	7916
COM 6	14	13	16	11753
COM 7	19	19	19	51027
COM 8	15	0	0	78317
all COMs Total	115	94	170	205103

[3] Due to the borders between COMs, some fractions were shared by two COMs. The total number of fractions (115) is thus lower than the actual sum of each COM's fractions (120). A further reduction of the fraction number needs to be made when only the ones for which fraction level data was available. In that case, all COM 5 fractions (all part of L'Aquila municipality) need to be subtracted - left are 106.

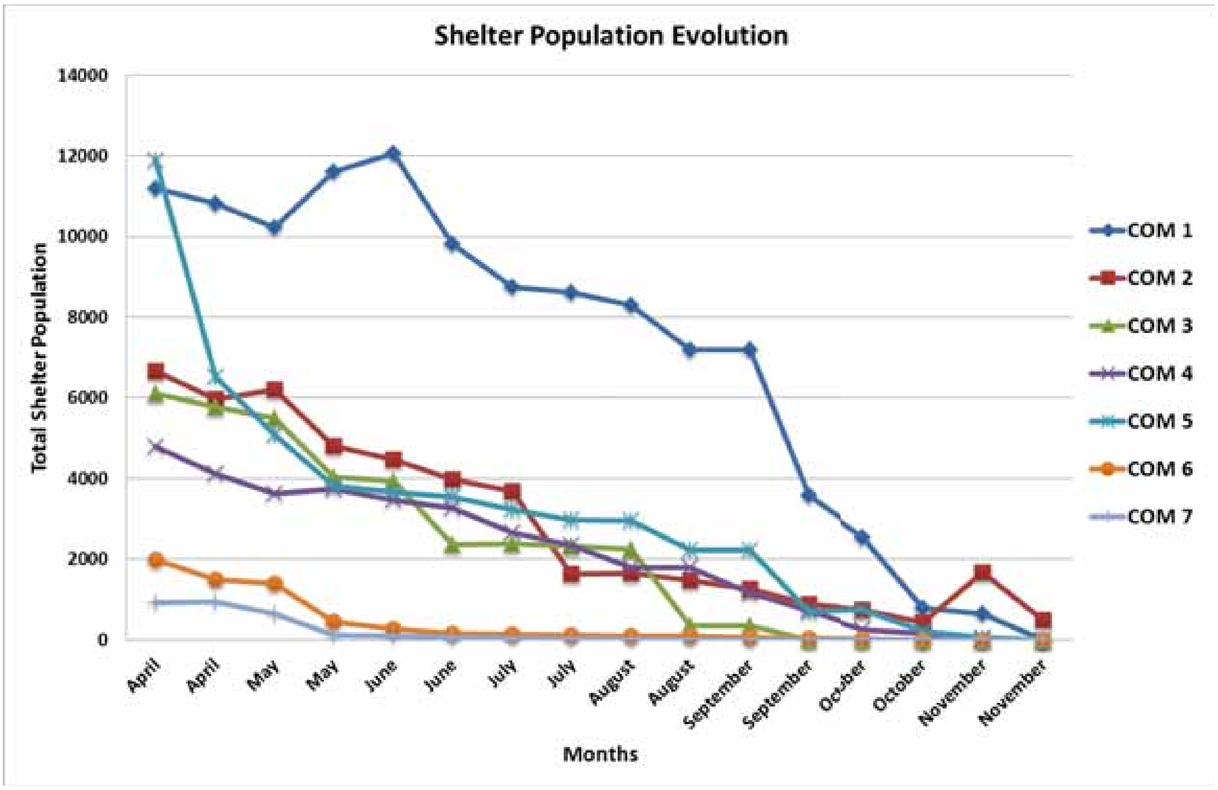


Fig. 6.10 Shelter Population Evolution in each COM

To link the socio-economic data to the observed shelter populations, the correlation coefficients between each (normalized) parameter and the shelter data per month were calculated. Surprisingly the results showed great variability on a COM level for almost all the socio-economic parameters. Throughout all socio-economic fields like education, age and professional status no consistent linear relationship could be established that was consistent for all COMs. A selection of the most significant variances from COM to COM can be found in Fig. 6.11 (since data was only available on municipality level for COM 1 and COM 5, it was not possible to perform statistical analysis with these two). As can be seen, the correlation with the elderly population (Age >65) follows a zig-zag movement through the COMs. The highest positive score can be found in COM 3, whereas the lowest is only undercut by the proportion of people working in the agricultural sector. In general, COM 4 showed the greatest overall variability (-0.91 to +0.92) and highest values of correlation for all parameters. Of all COMs, COM 4 has the greatest proportion of people working in the agricultural sector, which is reflected in the graph by the high influence of the parameter (correlation coefficient -0.91). Another distinctive feature that needs to be mentioned is the high positive correlation of dependents and people with higher education in COM 4. This effect could be due to the proximity to the L'Aquila University in L'Aquila municipality (COM 1).

The lowest correlation levels and variability were observed in COM 7. Most of the shelters here were sparsely populated compared to the other COMs, presumably due to the distance to the epicenter (50km+) and low intensities/impact sustained (see Fig. 6.11). The total population of all fractions, however, was appropriate to the large area in COM 7. Thus the low correlation to shelter population seems reasonable.

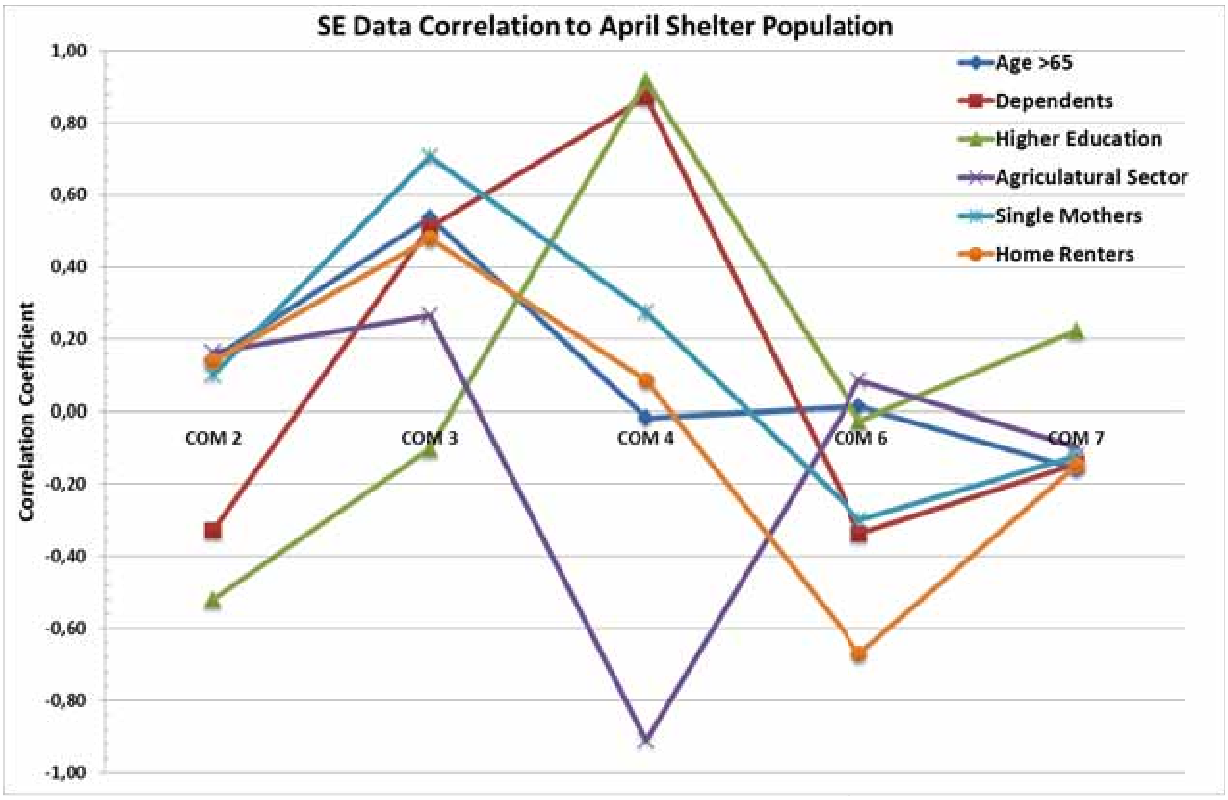


Fig. 6.11 Correlation between April Shelter Population and Key Socio-Economic Parameters

After this first exploratory analysis, an attempt to find global key indicators was made by calculating the correlation coefficient of all combined COM data. When computed like this, most values scatter around zero within an insignificant interval of [-0.1; 0.1].

To gain a more detailed impression of the significance of the different socio-economic factors, Geographically Weighted Regressions (GWR) were performed in a GIS software. The dependent variable was here the proportion of residents in shelters, explained by different socio-economic parameter proportions. The parameters to use were decided on the basis of the results provided by the correlation coefficients derived in the exploratory analysis. It was then made sure that the included indicators showed no sign of colinearity by performing a Moran's I test on the Residuals.

Table 6.7 provides an overview of several GWR runs with varying socio-economic parameters as input. As indicator of model validity the values for R-Squared, R-Squared Adjusted (R-Squared normalized by the degrees of freedom, i.e. number of input socio-economic parameters) and the Akaike Information Criterion coefficient are given. The best approach seems to be minimalistic: 62% of the variation in shelter population can be explained by only including the parameters Elderly (Age_65+), Illiterates (Illit) and Owners. This result of significant indicators is in accordance with the ones found in the literature mentioned in Section 6.2.2 (see

Table 6.4).

Table 6.7 Overview of several different GWR performed with varying input socio-economic parameters

Age_65+	EduL1	Illit	Depndts	LargFam	WithChld	MoChld	Agric	Owner	R^2	R^2 Adjusted	AICc
x		x						x	0.6199	0.4616	16.64
			x	x			x		0.5662	0.4312	15.28
x		x		x	x			x	0.5539	0.4203	16.52
	x		x			x		x	0.5442	0.3876	21.64
x		x					x	x	0.5321	0.3493	26.50
x	x		x			x		x	0.3967	0.2565	27.45

Keeping these parameters and adding further ones worsens the fit. Furthermore, substituting the aforementioned parameters by other socio-economic indicators, such as the proportion of people with only primary Education (EduL1), Dependents (Depdndts), Families with Children (WithChld), Single Mothers (MoChld) or people working in the Agricultural Sector (Agric), does not significantly improve the fit.

6.4.4 Model implementation

Multi-criteria decision analysis software was used to implement the methodology. The tool will allow stakeholders to display the Shelter Needs ranking of different neighbourhoods using various output and visualization formats. The user can assign and different importance (weights) to selected indicators and the tool can be used to discuss the weighting outcomes and interactively examine the variability of shelter demand in different areas to different weighting schemes, or to different earthquake scenarios.

The rankings for shelter demand after the L'Aquila earthquake are shown in Fig. 6.12 for the 8 Mixed Operations Centres (COM) which had the overall coordinating role in their own territories for all rescue and shelter provision operations. First the Displaced Persons Index (DPI) is obtained as the number of occupants living in uninhabitable buildings (BHI) amplified by the Desirability to Evacuate Criteria (Fig. 6.12c). In this case, the proportion of persons in uninhabitable buildings was not modelled following the methodology and taken directly based on observed values of partially usable and non-usable buildings in each of the 8 COMs from the AEDES Survey. Furthermore, in the calibration of the shelter model people living in the historical city centre were recommended to evacuate without consideration of unique building stability due to historical buildings and narrow alleys. Accordingly, the Desirability to Evacuate criteria accounts for forced evacuations in COM1, 2 and 5 (Fig. 6.12b).

To obtain the Shelter Needs Index shown in Fig. 6.12f, the Desirability to Seek Shelter Indicators (Fig. 6.12d) were obtained and amplified based on accessibility to shelter sites in the 8 COMs (Fig. 6.12e). Finally, the Shelter Needs Index (SNI) is obtained as the interaction between Displaced Persons Index and the Shelter Seeking Index (SSI). Fig. 6.13 shows how the modelling approach can be used to capture the actual shelter demand conditions (given as the observed number of people in shelter camps normalized by total population in each COM). For example, based on building usability alone COM 3 should have a lower shelter demand than COM 6 and 4. However given the high desirability to evacuate and seek shelter based on socio-economic indicators, COM3 obtains a more realistic ranking.

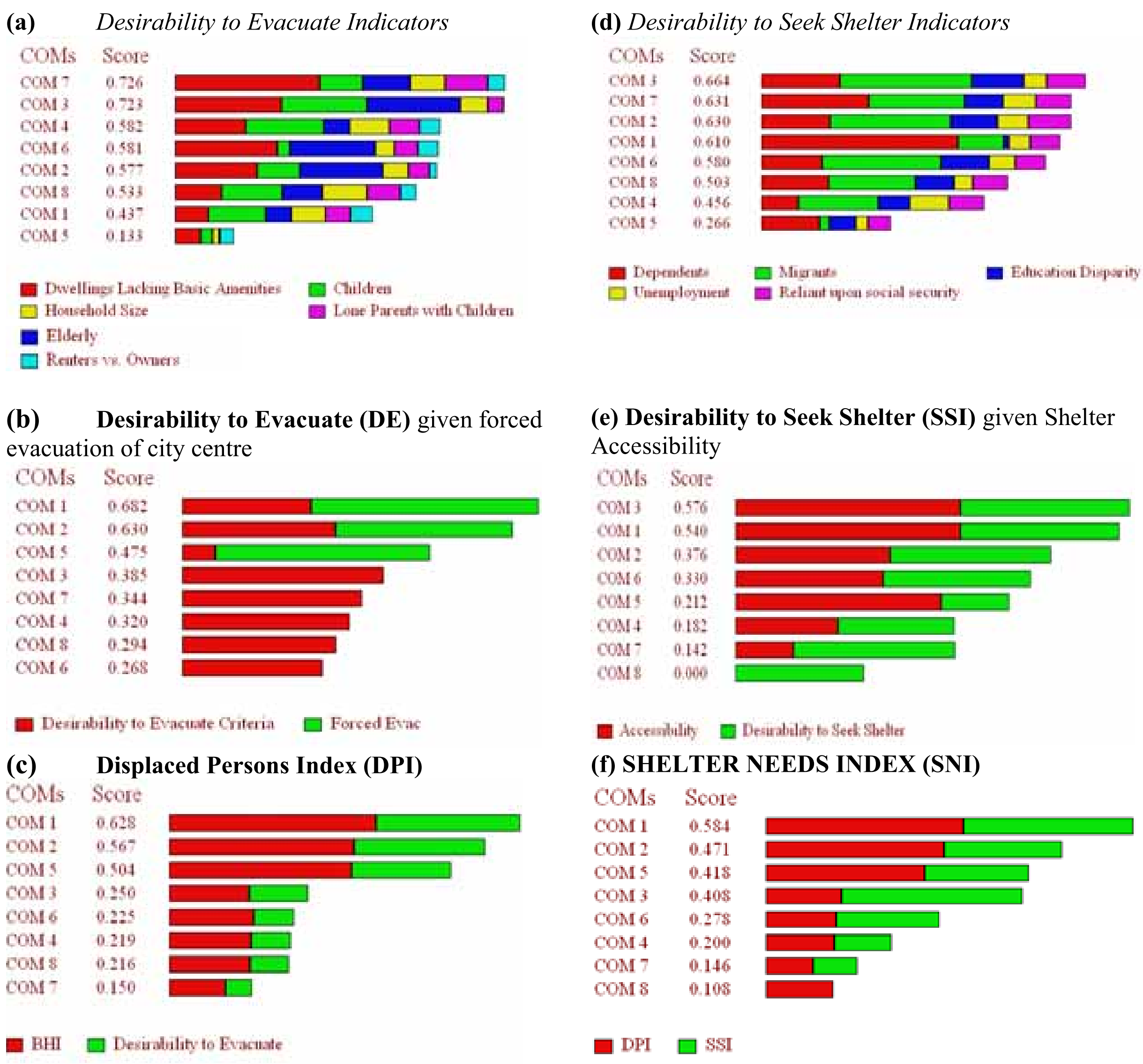


Fig. 6.12 Ranking of the Displaced Persons (left, 4a-c) based on the Building Habitability Index (BHI) and the Desirability to Evacuate (DE) Criteria. Ranking of the Shelter Needs Index (right, 4d-f) based on the Desirability to Seek Shelter (SSI) Criteria and the Displaced Persons Index (DPI).

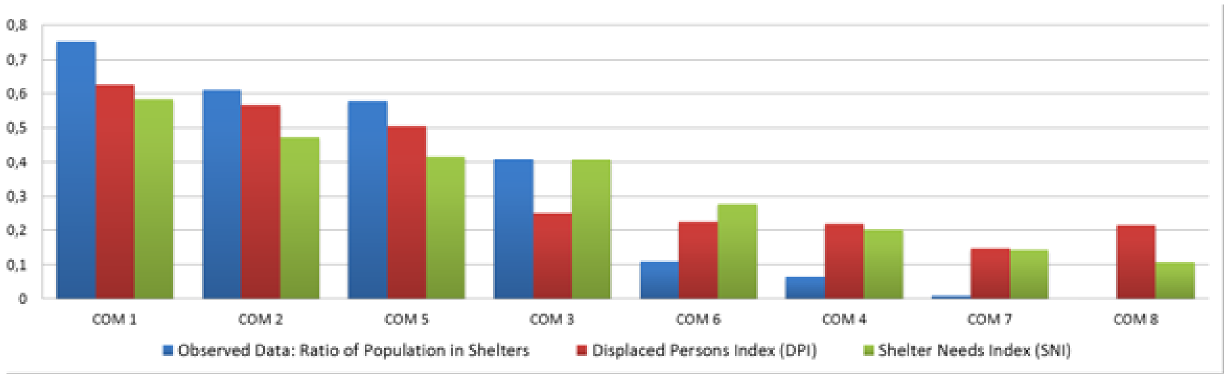


Fig. 6.13 Ranking of Shelter Needs Index (Left) based on Displaced Persons and the Desirability to Evacuate Seek Shelter criteria (Right)

7 Health impact model

7.1 INTRODUCTION AND BACKGROUND

7.1.1 Introduction

The destructive earthquake and tsunami of March 11 in Tohoku, Japan is a stark reminder of how overwhelming health impacts of such an event can be especially in terms of mass care of dislocated elderly populations (Fig. 7.1). The human losses incurred by the Tohoku event were extremely severe. As of September 30th, 2011, 15,815 were counted dead and 3,966 missing (19,781 in total). It is unknown how many victims may have died directly due to the earthquake, not counting tsunami losses. However, autopsies from the first 13,135 killed indicate that the earthquake-related shaking and damage alone did not kill many people (NPA, 2011). With about 23 percent of Japan's 127 million people older than 65 (Tanaka et al., 2009), Japan has the world's highest proportion of elderly in the world. The March-11th disaster highlighted the current and emerging issues of a "super-aging" society, especially the need for community-based support systems. Age therefore played a major role in the survival chances of people escaping the tsunami; as people age, they generally become less mobile. 77 percent of all of the victims counted up to this point were older than 50, and 46% of the victims (nearly half) were over 70 years of age Fig. 7.1 (Khazai, 2011).

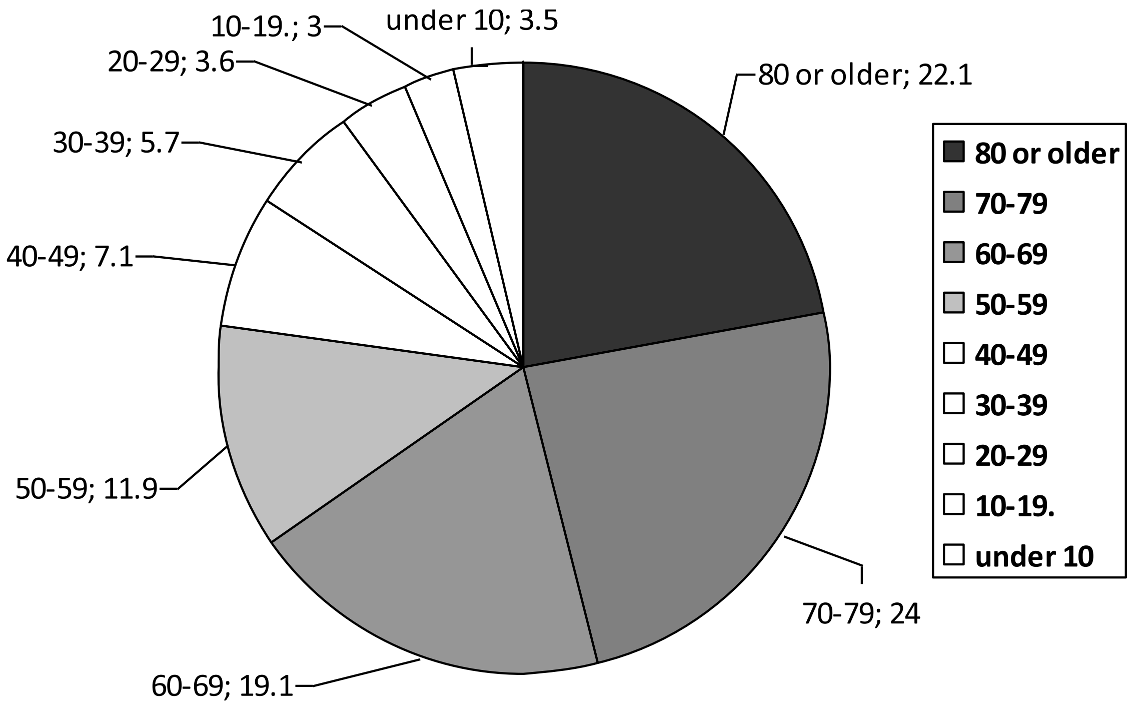


Fig. 7.1 Estimated fatalities by age for the dead and missing after the Tohoku earthquake, given NPA results from April 21st, 2011 as a date of reference.

Several other characteristic geographic, demographic, and cultural factors in Japan significantly worsened the health consequences from the Tohoku earthquake. The aid and medical response in the aftermath of the earthquake was complicated by the sheer scale of devastation, widespread damage to supply routes, loss of power- and communications networks, and concerns about radiation leaks from the Fukushima I nuclear power-plants. The existing shortage of healthcare resources in rural areas was exacerbated by the destruction of hospitals, clinics, and nursing homes, and the loss of healthcare staff. In-patients in the damaged hospitals had to be transferred to other hospitals. In some cases, this was extremely difficult, as hospitals and nursing homes for the elderly were located in the suburbs of the city, or in small towns which were relatively isolated from public transportation. The isolation of the affected area led to slower recovery efforts when compared to events such as the Great Hanshin-Awaji earthquake of 1995, which occurred in one of Japan’s largest cities. Finally, there was a public health concern about the increased risk of infectious diseases, including acute respiratory infections, influenza, tuberculosis, and measles, under crowded living conditions about diarrheal diseases and waterborne diseases that are typically sees after natural disasters (Khazai, 2011). In Japan, an increase in the morbidity rate associated with pneumonia was also reported after the 1995 Hanshing-Awaji earthquake Influenza was epidemic from February through March in Japan (Cunha et al. 2011).

7.1.2 Background

Health impacts include mortality and morbidity in term of injuries, disability, psychological effects, inadequate treatment of non-communicable and chronic diseases (e.g. problem with drug procurement), and increased transmission of infectious diseases (e.g., caused by parallel systems dysfunction such as water and sanitation, communication and transport). Systemic failures of **healthcare systems** and parallel infrastructure such as the water and sanitation system or emergency housing system as well as transport and communication system could lead to increased fatalities. Studies, models, and guidelines for hospital performance have largely focused on physical damage to structural systems and in some cases non-structural systems and equipment (e.g., HAZUS model, FEMA 2003). Yet from the perspective of societal impacts, the interest in measuring impact on health and healthcare systems is to provide estimates of **increased casualty** and capture the **performance of healthcare systems** in terms of providing post-event health care services. Fig. 7.2 summarizes impacts on health and health care systems adapted and modified from the EU Project MICRODIS which commenced in January 2011.

Casualty estimation methodologies (Coburn and Spence 2002, FEMA 2008) in Earthquake Loss Estimation (ELE) software provide estimates of both injuries and fatalities, which is a key input to assist planners in determining the resources required to deal with the increased surge in the patients. These methodologies quantify the number of fatalities and severity of injuries based on empirical data correlating building damage with casualties. Casualty estimation methodologies generally exclude casualties due to secondary causes, and do not account for injuries which can digress to fatalities as a result of systemic failures of healthcare systems and parallel infrastructure (e.g., transport, power, etc.). Furthermore, of systemic vulnerabilities in the healthcare or infrastructure systems can aggravate the overall health impact after earthquakes beyond the direct fatalities, for example, by the exaggeration of baseline diseases and increased transmission of communicable infectious diseases. Health impacts (mortality and morbidity, population in need of medical treatment) after earthquakes are also influenced or aggravated by social factors that are best described using the “umbrella term” social vulnerability. This includes latent vulnerability conditions in the at-risk population and systemic failure in the healthcare delivery system (Fig. 7.2).

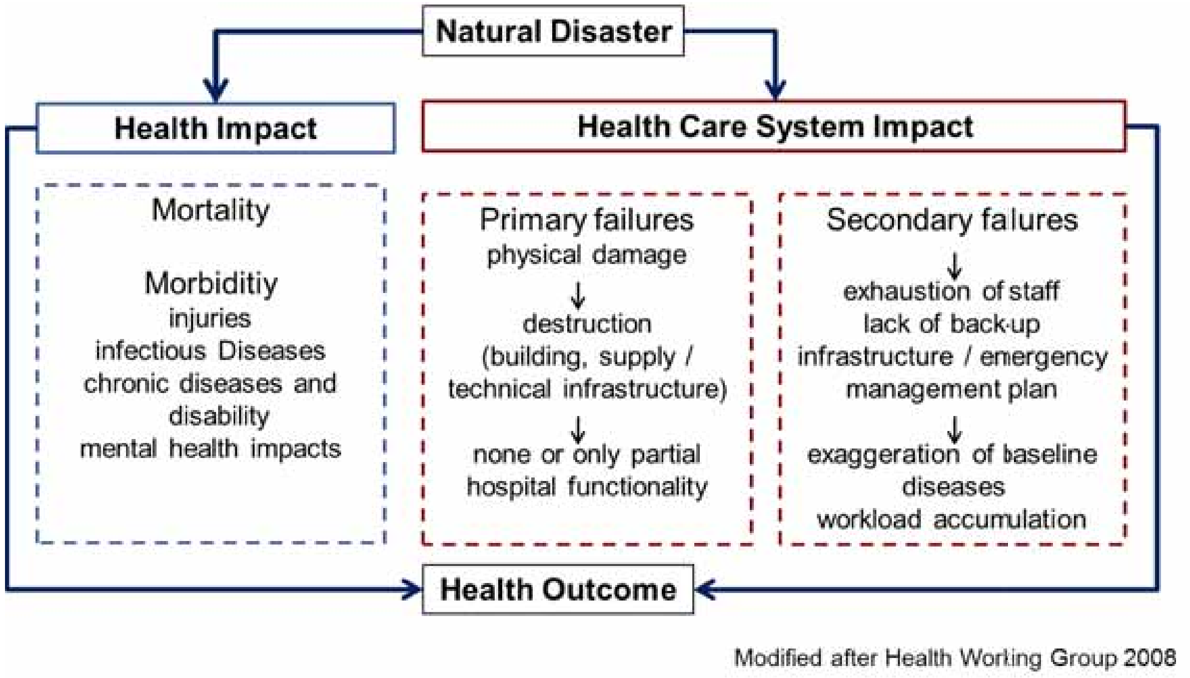


Fig. 7.2 Schematic of Impacts on Health and Healthcare Systems after Disasters

Although social vulnerability (or other social characteristics that are not part of the social vulnerability concept) is recognized as a key component for the aggravating health consequences of disasters, it is seldom linked to common formal and quantitative seismic loss estimates of injured people which provide direct impact on emergency health care services. Yet, there is evidence that earthquake health-care system impacts are also influenced and aggravated by social vulnerability, i.e. various characteristics of individuals, groups or social institutions that affect their ability to cope with health impacts after damaging earthquakes. Similarly, there are different social influences on the performance of health care systems after an earthquake both on an individual as well as on an institutional level. To link social impacts of health and health-care services to a systemic seismic vulnerability analysis, a conceptual model of social impacts of earthquakes on health and the health care systems has been developed.

7.1.3 Objectives

The aim of the Health Impact Model is to extend earthquake casualty estimation methods by developing a combined engineering and social science approach for modelling earthquake health impacts. As such, the approach presents a new method for modelling health impacts caused by earthquakes by linking casualty estimation methods and hospital functionality models typically used in Earthquake Loss Estimation (ELE) to key factors of individual health and health-care systems. The methodology provides an operational framework for implementing the different factors into an analytical hierarchical process model, and deploying them using indicators following the principles of Multi-criteria Decision Analysis.

The integrated approach for estimating post-earthquake health impact is derived by developing the following components;

1. A new methodology for estimating direct casualties from earthquakes has been developed;
2. A framework with main factors and parameters influencing individual health impacts of earthquakes based on literature research has been derived;
3. 22 indicators for which public statistical data is available for European countries with a high seismic risk related to health impacts after disasters has been identified;
4. A multi-criteria hierarchical model for quantifying post disaster health impact has been developed; and
5. The model and the available data have been implemented in a multi-criteria-analysis on national level with a special focus on social vulnerability.

The following sections will describe the basic elements of the health impact model and the methodology which links between socio-demographic, environmental, epidemiological and health behaviour parameters to increased health short- and mid-term health impacts.

7.2 BASIC ELEMENTS OF HEALTH IMPACT MODEL

This section sets out to explain the various contributing factors and their interactions, which is preceded by a definition of terms and explanation of framework used in the analysis.

7.2.1 Casualty estimation model (CEM)

An estimate of casualties (death and injuries) from future earthquakes is critical indicator in the preparation of emergency management and response plans and for facilitating the decision-making of institutions and organizations dealing with emergency support functions. Casualty estimates are also essential for medical and relief agencies and provide an initial scale for allocating resources in preparedness and response.

Most models provide “in-door” casualty estimates from structural building collapse and some provide non-structural casualties as a ratio of structural damage. It has been observed that 80% of fatalities attributed to earthquakes have been caused by the collapse of buildings (Coburn and Spence 2002). This has changed significantly with the past earthquakes in the last decade but the overall percentage has stayed around the same with Marano et al. (2010) from 2200 events and Daniell (2010) from 6500 events both showing that around 75% of deaths are due to earthquake shaking. As the construction of RC buildings is increasing, the portion of casualty victims in RC buildings is rapidly increasing. This can also be attributed to the fact that RC structures built in the poorer countries are highly vulnerable and when they collapse they are considerably more lethal and kill a higher percentage of their occupants than masonry buildings.

Sources of Uncertainty in Casualty Estimation Models:

- Casualty statistics (types and numbers) from past earthquakes are often inconsistent and unreliable (i.e., lack of standardization of injury data and established methodologies for reporting casualty data).

- Casualty statistics very often do not provide information about cause of death (e.g., structural, non-structural, other causes)
- Casualty statistics do not discern which building type (e.g., RC, Masonry, etc.) the casualty figures come from
- Lethality Ratios used in CEMs are often engineering factors and not based on empirical/historic data
- Uncertainties in population per building (i.e., uncertainties and incompleteness of data relating occupants to building volume)
- Uncertainties in building occupancy at the time of earthquake (day and night variability as well as seasonal variability due to inflow of tourists or students)

As a result of the many uncertainties existing casualty models have failed to convey the degree of confidence to which estimates are given. This is extremely important in any decision making process as administrators or policy makers must be aware of the margins of error to make informed decisions. The seismic community has so far failed to disseminate data and stimulate responses from national and government organizations effectively (LessLoss, 2007).

Casualty estimation model in SYNER-G

The model developed here provides an initial (direct) casualty estimate for occupants of buildings at the time of earthquake based on an original idea developed by Coburn and Spence (1992). However, the casualty model developed in SYNER-G has several new components and considerations compared to available casualty models. The proposed casualty model computes casualties directly caused by building damage for *each* class of buildings using “Casualty Ratios” (CR) which are optimized based on historical earthquake data (described in detail later). CR is defined as the ratio of the number of people killed to the number of occupants present in collapsed buildings of that class. Multiplying the CR for each building damage class by the number of occupants in buildings of that damage class, the number of deaths for that building type can be estimated. Casualty ratios are assessed for three different building super-classes based on the vulnerability in each building typology *for producing casualties*. The features of the SYNER-G Casualty Model are described below:

- The model estimates casualties from **all damage states**. Most casualty models determine casualty as a function of building collapse only. While building collapse is the dominant factor of casualties, So and Spence (2010) have shown with historic data (Pakistan, Indonesia and Peru) that casualties can also occur in moderate (D3) and low (D2) damage states (Fig. 7.3).
- The model estimates casualties using **semi-empirical Casualty Ratios**. The process of determining casualty or lethality ratios is often unclear and in many cases it is an engineering judgement based on historic evidence. The model here proposes a methodology for deriving and optimizing casualty ratios for regions with comparable building construction.
- In addition to determining casualty ratios as a function of building damage, the model also considers **Seismic Intensity**. It has been shown that casualties produced at the same building damage level are different for different levels of seismic intensity. Also it has been shown that seismic intensity correlates well with casualties (Spence and So, 2010).

- The model estimates casualties by proposing a **"Building-Casualty" Super-class** based on the propensity of different building typologies in producing casualties.

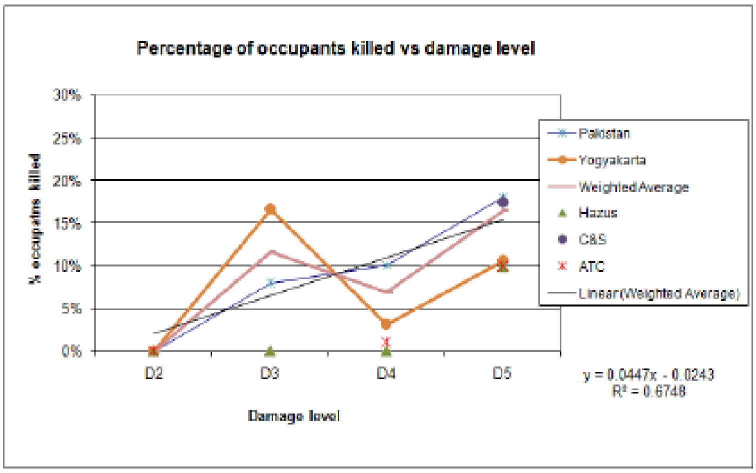


Fig. 7.3 Graph showing the regression relationship for percentage of occupants killed at different buildings damage states (from Spence and So, 2010)

The casualty model is composed of the following elements each of which are described in the corresponding sections below:

- Building Occupancy
- Building Damage Probability Matrices
- Seismic Intensity
- Buidling-Casualty Superclasses
- Casualty Damage Ratios

Building Occupancy

Building occupancy varies considerably based on building volume, building use, time of day and season. Building volume is estimated as the footprint of the building and the number of stories. Occupancy is assessed in different building *Occupancy Types* (e.g., residential, commercial, educational, industrial, hotel, commuting). The exposure for a given time and season also has to be evaluated using local data or a first approximation has to be made for both the casualty and displaced persons analysis. Coburn and Spence (2002) temporal occupancy model, which gives the distribution of population during different times of the day, has been used to obtain the population in different building types at the time of the earthquake. Thus, the total population in all buildings of a given Occupancy Type is given by the following relationship, given by Eq. 7.1:

$$PO = F \times Total\ Population \tag{7.1}$$

where, F is percentage of population residing in a given occupancy type at a particular time. The Coburn and Spence temporal occupancy model is based on global data. However, there are variations in the temporal model for different countries, regions, urban or rural settings that have to be accounted for. As an alternative, the variations of exposure over the day (short-term), over the week (mid-term) and over seasons (long-term) in Italy are considered for the Italian casualty model application, based on a study by Zuccaro and Cacace (2010) using national and municipal data (Fig. 7.4).

Building Damage

The *evaluateBuildingDamage* method in SYNER-G illustrated qualitatively in Fig. 7.5 is used to obtain the building damage probability matrices for four structural damage states (none, light, severe, and collapse). The damage state is determined for all buildings within each typology by sampling a standard uniform variable. The value between 0 and 1 falls within one and only one of the intervals defined, at the intensity value obtained for the cell centroid from the seismic hazard model, by the sets of fragility curves for increasing damage states stored for the typology in the property *fragilitySets* of the cell. This is the damage state of the buildings of this type within this cell for the event.

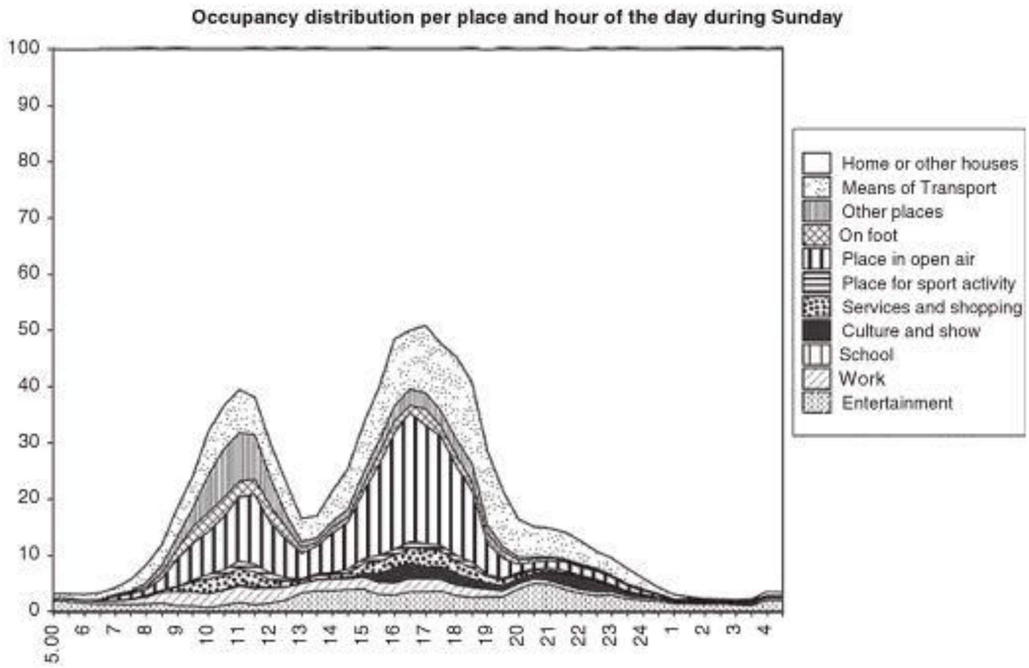


Fig. 7.4 Occupancy distribution using data from the Municipality of Torino (Zuccaro and Cacace, 2010)

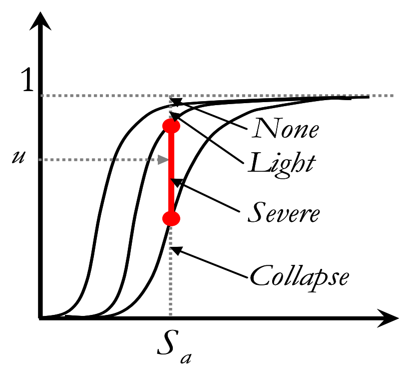


Fig. 7.5 The evaluateBuildingDamage method for determining Building damage in SYNER-G.

A comparison has been conducted of studies estimating casualties for large earthquakes worldwide using empirical approaches based on seismic intensity (Level 1 analysis) and studies where casualties are estimated using building damage derived from fragility sets (Level 2 analysis). It is interesting to note that overall if the level 2 damage-based casualty estimates were not worse, they did not estimate casualties better than the level 1 analysis. This is reinstated by many tests by PAGER and ELER.

Building-Casualty Super-classes

For equal structural damage levels the probability of casualties is influenced by the building typology and geometry. Casualty and building damage data has been collected for over 70 municipalities (*comuni)* for three large Italian earthquakes. Casualty data in CATDAT (Daniell, 2011) was available for 214 municipalities (deaths and injured) for Irpinia 1980, 26 municipalities (deaths) in Friuli 1976 and 8 municipalities for L'Aquila 2009 but the damage data in many cases has not been able to be sourced. Based on the building type designations in the survey data, 3 "Superclasses" of building typologies based on their potential for producing casualties have been defined as shown in Table 7.1.

Table 7.1 Building-Casualty Superclasses defined for the Italian events

Casualty Potential	Superclass Category	Construction Typology	Description
very high	1-BC	Reinforced Concrete	Mid-rise and High-rise (> 3 story) reinforced concrete frame buildings; of in-situ reinforced filler slabs with ceramic plank fillers
high	2-BC	Stone, brick or block masonry walls with reinforced concrete floors/roofs	Field stone and Hewn stone walls; manufactured masonry units, concrete block, brick or hollow ceramic block, of three stories or more and have reinforced concrete floors. Also many of the traditional masonry buildings that have additional stories added in new materials without strengthening or supporting structure
moderate	3-BC	Stone, brick or block masonry walls with timber rubble masonry, timber or steel joist floors/roofs	Field stone and Hewn stone walls; manufactured masonry units, concrete block, brick or hollow ceramic block, of one to three stories and have reinforced concrete floors.

The choice of the superclasses are based on classifications of casualty ratios produced by different building types in the published literature and knowledge of the reduction of volume in different building types which influences the number of trapped people and hence casualties. It should be emphasized that building vulnerability classes (e.g., EMS classes A-F) do not represent the potential to produce casualties in buildings and only represent the vulnerability of buildings to damage. The superclasses discern between different building classes of equal damage state (e.g. slight or collapse) in terms of the relative casualty level which can be produced in each of the building classes. However, as no empirical data as such is available to validate the choice of the superclasses, a sensitivity analysis is performed to determine the influence of change in superclasses.

It should be noted that 4-BC (low) and 5-BC (very low) will be used for other typologies not found in the Italian settings of the three earthquakes. Again, this will need to be validated with future work.

Casualty Ratio

The semi-empirical model considers historic earthquake data from 3 major Italian earthquakes – 1976 Friuli, 1980 Irpinia and 2009 L'Aquila - as the basis of deriving empirical "casualty ratios" used in the model (the current model is based on data from Friuli and Irpinia, and data for L'Aquila is being collected). The casualty model does not directly account for aggravating factors which can increase post-earthquake mortalities, such as health preconditions in the poor and vulnerable, or increased fatalities as a result of hampered rescue and relief efforts or non-functioning of health care facilities. These factors are nevertheless accounted for in the multi-criteria Health Impact Model (explained later) where estimated direct casualties is used as one of the inputs.

Casualty Ratios used in Coburn and Spence (2002), Spence and So (2010), ELER (Erdik et al, 2008), and ATC-13 (HAZUS) were evaluated. As Casualty Ratios are very specific to the particular building typologies, building practices and living arrangements in each region, a Global or Pan-European casualty model is not feasible. The aim is to produce a semi-empirical approach by which Casualty Ratios would be derived from empirical data on building damage classes and Super classes of building typologies. In the current approach Casualty Ratios for an Italian Model are obtained by optimization with casualty and damage data for 3 Italian earthquakes (1976 Friuli, 1980 Irpinia, 2009 L'Aquila). All three events occur in comparable settings and are night-time events (Friuli and Irpinia around 8pm and L'Aquila around 3am). It should be noted that the present casualty ratios are based only on Friuli and Irpinia as the full L'Aquila data is missing and was not included in the model). The approach of estimating casualty ratios can be described in the following steps:

- The building stock of any region is grouped in terms of its distribution in Building-Casualty super classes (Table 7.1) and 6 EMS Vulnerability Classes (A-F) at the event year.
- A database for each historic earthquake event is constructed, where for each administrative unit (e.g., municipality) the following parameters are captured:
    - Number of dead and injured in each Municipality
    - Number of total buildings in each Municipality
    - Population at time of event for each Municipality
- Distribution of Building Damage states (none, slight, moderate, severe, collapse) in each Municipality
- Distribution of Seismic Intensity (EMS scale) in each Municipality
- Allocation of Building Damage states for each Building-Casualty superclass (1-BC, 2-BC and 3-BC) and Building Vulnerability EMS class (A-F).

- Allocation of Seismic Intensity for each Building-Casualty superclass (1-BC, 2-BC and 3-BC) and Building Vulnerability EMS class (A-F).
- Allocation of Total Building Occupancy for each Building-Casualty superclass (1-BC, 2-BC and 3-BC) and Building Vulnerability EMS class (A-F).
- Using the above parameters the number of dead is simulated in an initial run with an *assumed* Casualty Ratio matrix using values published in the literature Coburn and Spence (2002), Spence and So (2010) and ATC 13.

Casualty ratios are optimized in subsequent iterations using an optimization algorithm so that a best-fit is achieved between simulated and surveyed casualty numbers. The optimization algorithms use constraints and restrictions which are derived from common assumptions (e.g., the casualty ratio for moderate damage state should not be greater than casualty ratio for collapsed damage state). Lower and Upper boundary functions are also defined based on Coburn and Spence (2002), Spence and So (2010), ATC-13 as well as other casualty estimation methodologies. Using the optimized Casualty Ratios for the region, the number of deaths are determined for that region, using the mean inhabitants by building type, and occupancy rate by day and night. Based on data compiled from CATDAT (Daniell, 2012) for 56 municipalities (*comuni)* for the three large Italian earthquakes, the following preliminary semi-empirical casualty ratios were derived and presented in Table 7.2 (using whole intensity system), Table 7.3 (using half-scale intensity system) for 3 Building-Casualty types, and 6 damage levels.

Table 7.2 Casualty Ratios using whole intensity system

Intensity 6	D0	D1	D2	D3	D4	D5
1-BC	0	0	0	0.0011	0.0027	0.0067
2-BC	0	0	0	0.0005	0.0013	0.0033
3-BC	0	0	0	0	0.0007	0.0017

Intensity 7	D0	D1	D2	D3	D4	D5
1-BC	0	0	0.0009	0.0021	0.0053	0.0133
2-BC	0	0	0	0.0011	0.0027	0.0067
3-BC	0	0	0	0.0005	0.0013	0.0033

Intensity 8	D0	D1	D2	D3	D4	D5
1-BC	0	0.0009	0.0021	0.0053	0.0133	0.0333
2-BC	0	0	0.0011	0.0027	0.0067	0.0167
3-BC	0	0	0.0005	0.0013	0.0033	0.0083

Intensity 9	D0	D1	D2	D3	D4	D5
1-BC	0	0.0048	0.0073	0.0182	0.0454	0.1136
2-BC	0	0.0024	0.0036	0.0091	0.0227	0.0568
3-BC	0	0.002	0.003	0.0076	0.0189	0.0473

Table 7.3 Casualty Ratios using half intensity system

Seismic Intensity = 6						
	D0	D1	D2	D3	D4	D5
1-BC	0	0	0	0,000701	0,001721	0,004271
2-BC	0	0	0	0,000425	0,000829	0,002104
3-BC	0	0	0	0	0,000446	0,001084
Seismic Intensity = 6.5						
	D0	D1	D2	D3	D4	D5
1-BC	0	0	0	0,00119	0,002975	0,007395
2-BC	0	0	0	0,000595	0,001445	0,003655
3-BC	0	0	0	0	0,000765	0,00187
Seismic Intensity = 7						
7	D0	D1	D2	D3	D4	D5
1-BC	0	0	0,000612	0,00153	0,003902	0,009716
2-BC	0	0	0	0,000765	0,001913	0,004896
3-BC	0	0	0	0,000383	0,000995	0,002448
Seismic Intensity = 7.5						
7,5	D0	D1	D2	D3	D4	D5
1-BC	0	0	0,00102	0,002635	0,00663	0,01666
2-BC	0	0	0	0,00136	0,003315	0,00833
3-BC	0	0	0	0,00068	0,0017	0,004165
Seismic Intensity = 8						
8	D0	D1	D2	D3	D4	D5
1-BC	0	0,000689	0,001607	0,004055	0,010175	0,025475
2-BC	0	0	0,000842	0,002066	0,005126	0,012776
3-BC	0	0	0,000425	0,000995	0,002525	0,00635
Seismic Intensity = 8.5						
8,5	D0	D1	D2	D3	D4	D5
1-BC	0	0,00187	0,00323	0,00816	0,0204	0,051085
2-BC	0	0,00068	0,001615	0,00408	0,0102	0,025585
3-BC	0	0,000595	0,001105	0,00289	0,007225	0,018105
Seismic Intensity = 9						
9	D0	D1	D2	D3	D4	D5
1-BC	0	0,003672	0,005585	0,013923	0,034731	0,086904
2-BC	0	0,001836	0,002754	0,006962	0,017366	0,043452
3-BC	0	0,00153	0,002295	0,005814	0,014459	0,036185
Seismic Intensity = 9.5						
9,5	D0	D1	D2	D3	D4	D5
1-BC	0	0,006579	0,010022	0,025092	0,062501	0,156443
2-BC	0	0,00329	0,004973	0,012546	0,031289	0,078183
3-BC	0	0,002754	0,004131	0,010481	0,02601	0,065102

Deriving semi-empirical casualty ratios based on 56 data points and 2 events (Friuli and Irpinia) the model better predicts recorded deaths using the whole intensity system, rather than the half intensity system. As the empirical data points increase it is expected that the half intensity system will provide better estimates.

Given the Casualty Ratio tables above, the number of deaths (N_d) is determined using the following expressions:

$$N_d = \sum_{t=1}^{3} \sum_{d=1}^{6} \sum_{i=1}^{5} N_{t,d,i} \; CR_{t,d,i} \; NO_t \qquad (7.2)$$

where:

t = building-casualty type (t = 1-BC. 2-BC. 3-BC)

d = damage level (d = D0, D1, D2, D3, D4, D5)

i = seismic intensity level (i = VI, VII, VIII, IX, X)

$N_{t,d,i}$= number of buildings of type *t* having damage level *d* at seismic intensity level *i*

$CR_{t,i}$ = proportion of deaths by building type, damage level and seismic intensity

NO_t = number of occupants (at the time of the event) by building type *t*

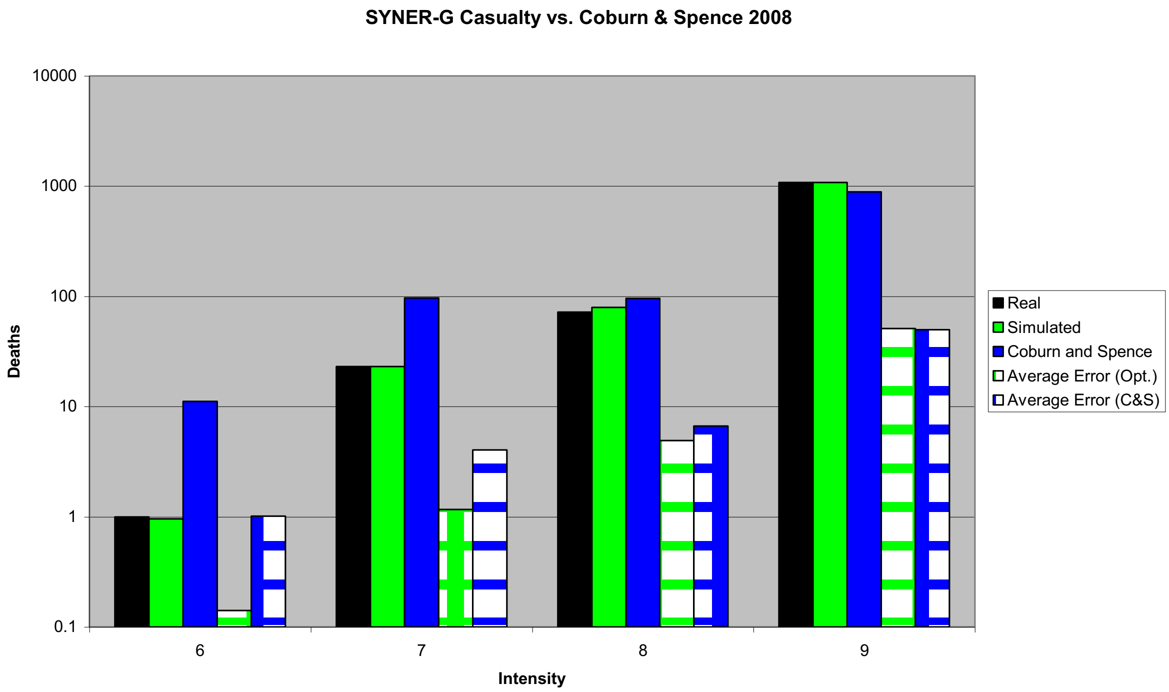


Fig. 7.6 Comparison of SYNER-G and Coburn and Spence (Less Loss) Casualty Models for Italy

Combining the death records for the Friuli and Irpinia events according to seismic intensity, the casualty model proposed here was compared against the 2008 Coburn and Spence casualty model developed for LessLoss (Casualty Ratios only in D5 damage state). The results are shown in Fig. 7.6 where the recorded death numbers are shown as "black" bars for each seismic intensity area. The "green" bar shows the simulated fatalities using the model proposed here, and the "blue" bar shows the simulated fatalities using Casualty Ratios proposed in LessLoss by Coburn and Spence. The "hashed green" and "hashed blue" bars show the average errors in the proposed model and Coburn and Spence, respectively.

As the graph is plotted on a logarithmic scale, the relative comparison of both models is best seen through the average error bars. It can be seen that Coburn and Spence overestimate deaths at low seismic intensities, while they at higher intensities the average error is comparable.

7.2.2 Hospital functionality model

Several researchers have proposed methods, whereby interrelated systems on hospital functionality – structural, non-structural, and personnel – are assessed according to performance levels indicating functionality within each system (Holmes and Burkett, 2006; Chang, 2008, Lupoi et al., 2008). However, the vast literature available in the public health and disaster emergency medicine domains, have so far not been considered in integrated earthquake loss estimation frameworks and models.

Studies, models, and guidelines for hospital performance have largely focused on physical damage to structural systems and in some cases nonstructural systems and equipment (e.g., HAZUS model, FEMA 2003). Yet from the perspective of social impacts, hospital performance should be measured in terms of capacity to provide health care services. The previous study (Lupoi et al., 2008)by SYNER-G consortium members at UROMA presents a good basis for the SYNER-G healthcare model based on the seismic risk analysis of a single health-care facility. A detailed system analysis is required and is being undertaken as an activity of WP2-WP5. This section briefly illustrates how the **capacity** terms are evaluated. In particular, the capacity term is the result of three contributions, coming from the three *macro-components* (m/c) making up the hospital system: the physical m/c (structural and non-structural element of the facility), the organizational m/c (the procedure in the emergency plans) and the human m/c (skill and training of the operators using the facilities and equipment according to the procedures). The Hospital treatment capacity, yielding the number of surgical treatments that can be carried out per hour, is expressed as the product of three factors, divided by the average treatment duration in hours:

$$\boldsymbol{HTC} = \frac{\boldsymbol{\alpha\beta\gamma}}{\boldsymbol{t_m}} \tag{7.3}$$

The three factors correspond to the three already mentioned m/c:

- $\alpha \rightarrow$ organisational m/c: measures the effectiveness of the emergency plan
- $\beta \rightarrow$ human m/c: measures quality/skill/training of the staff
- $\gamma = \gamma_1\gamma_2 \rightarrow$ physical m/c
- γ_1 number of operating theatres still operational after the event
- γ_2 system boolean function: 1 if essential medical services (minimum subset of all the medical services required to support the operating theatres) are available, 0 otherwise.

The quantitative assessment of the first two factors requires interaction with specialists from outside the Engineering disciplines, and direct contact (interview) of the local staff. For the evaluation of the third factor, it is necessary to establish the conditions under which the hospital (system) can keep on providing its function (essential medical services). These are:

- Structural and non-structural damage are compatible with continued functioning.

- Medical equipment and essential utilities (electric power, water, medical gases, etc) are available.

Establishing whether the above conditions are met requires checking that all necessary subsystems remain operational. This is done by describing the whole hospital system with a fault tree. The evaluation of the probability distribution of HTC is carried out by simulation. To limit the computational effort associated with the simulation this is split into two steps. In the first one a limited number of recorded ground motions is used to carry out nonlinear time-history analysis on a structural model of the building(s) housing the hospital and to collect samples of all the correlated response quantities (e.g. floor drifts, floor accelerations, columns shears, etc.) needed to establish whether the structure stands after the earthquake and the non-structural elements and equipment are operational. The second step consists of a Monte Carlo simulation with structural responses sampled from a joint model fit to the responses collected in the first step, and structural and non-structural capacities sampled from their respective fragilities, to obtain the state of each component and that of the system as a whole (according to the logic spelled out in the fault tree).

The methodology described above by Lupoi et al. (2008), is based on a detailed systems analysis of hospital systems. The scale of analysis is broader in SYNER-G and the methodology has to be up-scaled to urban and regional level of analysis. Thus factors α and β will be determined based on the closest proxy indicators available from the Urban Audit database or the option for specific user input in case the data is available in a local implementation. Parameter γ also has to be assessed at this broader scale and it is proposed that models on hospital performance WP2-WP5 are based on an approach (based on from Chang, 2010) whereby each of four interrelated systems – structural, nonstructural, lifelines, and personnel – is assessed according to four performance levels indicating functionality. Performance levels are:

1. limited or no damage (or, for personnel, all available)
2. minor damage that does not affect facility operations (for personnel, a few unavailable)
3. damage that affects the facility's operations (for personnel, substantial numbers unavailable)
4. extensive damage requiring immediate evacuation (for personnel, majority unavailable)

Performance levels of the structural, nonstructural, lifelines, and personnel systems influence overall facility-level functionality. Facility functionality should also be assessed according to four classes:

1. Fully functional (F.F.) = Facility functionality is at normal levels.
2. Functional (F) = Facility functionality is lower than fully operational; however, none of the sections' functionality is interrupted.
3. Affected functionality (A.F.) = Some sections are not able to provide normal services due to damage, but facility still able to provide some emergency services.
4. Not functional (N.F.) = Facility is not functional and must be evacuated.

Furthermore, **external lifelines** such as municipal water supply are known to influence hospital functionality, even where backup systems may be in place. Very little documentation exists, however, on the effects of external lifeline outages on the performance of health care facilities after past earthquakes or similar disasters. Due to lack of data, a simple method will be developed here to account for external lifeline disruption: if a facility experiences loss of at least one external lifeline (e.g., electric power or water), then the functionality class probabilities are adjusted up one level of severity (adapted from Yavari et al. 2008).

7.2.3 Accessibility/transport system

Systemic failures in healthcare delivery, hampered rescue and relief efforts and lack of access to food and shelter, can lead to the exaggeration of baseline diseases and increased transmission of communicable infectious diseases. A full analysis of accessibility to hospital systems has been described in Chapter 5 and the healthcare accessibility index will be integrated into the health care model.

7.2.4 Vulnerability factors influencing health issues

The vulnerability and coping capacities of 'at risk' populations affects the complexity of calculating health impacts of earthquakes. Although there is growing evidence that vulnerable population groups (e.g., elderly, populations with chronic disease and disabilities) create a great burden during and in the aftermath of disaster, there is currently a lack of knowledge and information about the burden of natural disaster on chronic health problems. Most of the examples come from the experience in Katrina, with the specific characteristics of Louisiana (Daniels, 2006). In addition, research on the health prospect of people who have become disabled because of a disaster injury is scarce. Finally, while mental health has been recognized as an important issue in the aftermath of disasters, most studies have taken place in developed countries. Mental health aspects have been rarely studied in Asian countries and a few publications from Bangladesh, Sri Lanka, Indonesia, China, Korea, India and the Philippines (e.g. Kar et al. 2007; Kar and Bastia 2006) appeared only recently.

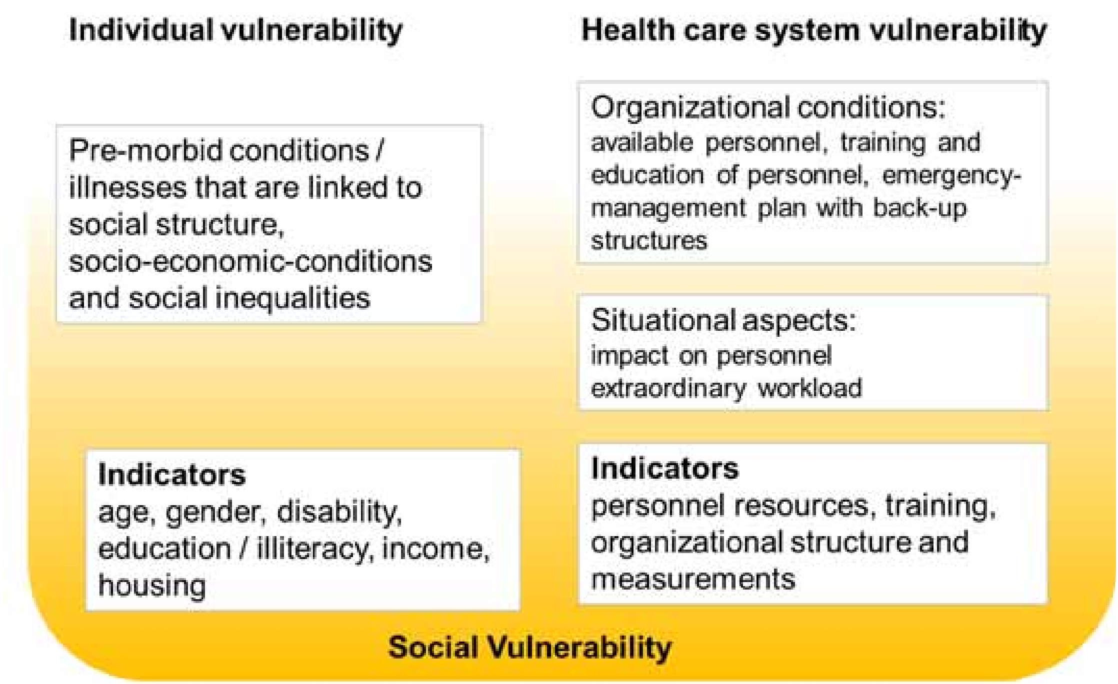


Fig. 7.7 Social Vulnerability and Health Impacts

Several key indicators of individual and health care system vulnerability that can aggravate the overall health impact after a disaster are presented in Fig. 7.8. To identify the most critical factors determining post-disaster health impacts a comprehensive literature survey was carried out looking at 65 unique publications world-wide related to health and health system impact from different type of disasters from 1992 to 2012. The literature survey and resulting indicators are part of the Technical Report D4.2 in the SYNER-G project (Khazai et al., 2012a).

In order to test the approach in principle, five main criteria influencing health impact were identified in order to structure the individual indicators. The five main criteria shown in Fig. 7.9 include:

1. Criteria 1: Social vulnerability factors,
2. Criteria 2: Environmental health factors,
3. Criteria 3: Baseline health status,
4. Criteria 4: Healthcare capacity factors,
5. Criteria 5: Infrastructural factors

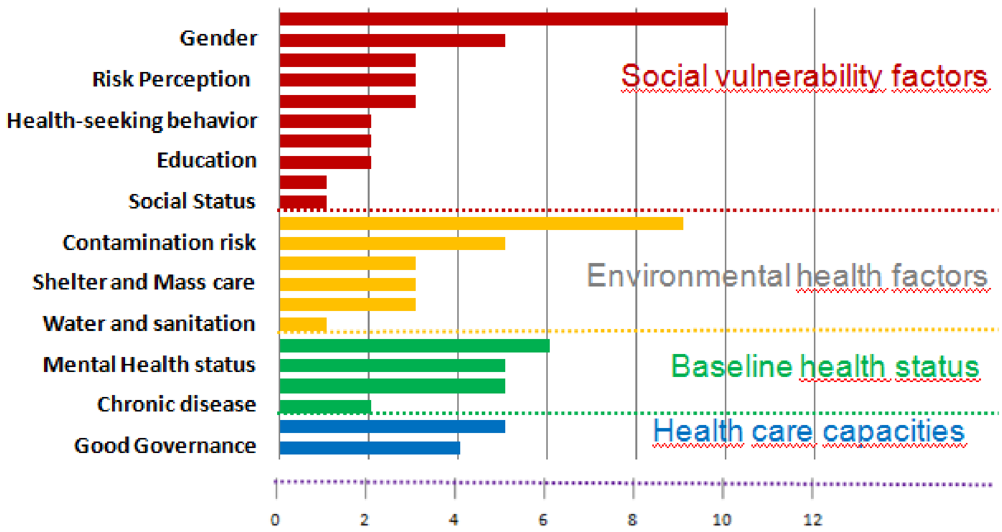


Fig. 7.8 Factors influencing individual earthquake health impacts based on nominations from 65 original papers (1992-2012)

The selection of individual indicators along each one of these main criteria is dependent on scale, context and availability of data. While the main explanatory criteria can be the same for a regional or urban level analysis, at the urban scale the underlying health vulnerability factors could manifest themselves into a set of different indicators. In this study, both regional level indicators as well as urban and sub-urban indicators were investigated and were selected for each of the main criteria identified in the literature research. For the urban scale of analysis the EUROSTAT Urban Audit is the main reference for identifying indicators. This is in line with the approach adopted in SYNER-G for harmonizing a set of indicators that can be implemented in Europe for sub-city districts. However, the regional scale of analysis allows capturing health parameters which are not differentiated at the urban level and provides a broader measure of health impact than the local-scale alone. For these indicators the EUROSTAT data was used in addition to data from other sources including UNDP, WHO, World Bank, CIA.

Table 7.4 Required variables for the Health Impact model and availability on Urban Audit

Required indicators		Available indicators on URBAN Audit (at SCD)	
Code	Indicator	Code	Name
Social Vulnerability Factors			
AGE	Elderly, 65 years and above	DE1028V DE1055V	Total Resident Population 65-74 Total Resident Population 75 and over
SEX	Gender (being female)	DE1003I	Female Resident Population
AHH	Household size Presence of children	DE3004I	Average size of households
MIN	Race and ethnicity; Belonging to the minority	DE2005I DE2006I	Prop. of residents who are not EU Nationals and citizens of a country with a high HDI Prop. of residents who are not EU Nationals and citizens of a country with a medium or low HDI
INC	Income		Total Number of Households with less than half of the national average disposable annual household income Total Number of Households reliant on social security benefits (>50%) Individuals reliant on social security benefits (>50%) Median disposable annual household income (Euro)
UNE	Occupation status	EC1020I	Unemployment rate
EDU	Skills and education	TE2025V TE2028V TE2031V TE2025I	Number of residents (aged 15-64) with ISCED level 0, 1or 2 as the highest level of education Number of residents (aged 15-64) with ISCED level 3or 4 as the highest level of education Number of residents (aged 15-64) with ISCED level 5 or 6 as the highest level of education Prop. of working age population qualified at level 1 or 2 ISCED
SOL	Having strong social networks; extended family (solidarity)	DE1062I	Total annual population change over approx. 5 years (by sex and age)
Baseline Health Factors			
MOR	Mortality	SA2029I SA2030I	Crude Death Rate per 1000 Citizens Mortality Rate of Age 65-

Comparing the required factors from the literature survey of vulnerability indicators with those variables covered through Urban Audit on the Sub-City District (SCD) level it is shown in Table 7.4 that indicators are available for two categories: social vulnerability and baseline health.

It can be concluded that while the Urban Audit provides socioeconomic, demographic, and further data on SCD level covering 369 cities all over Europe, it does not satisfy the demand for the different health impact criteria identified in the literature. The Urban Audit does not describe relevant health parameters describing environmental health factors, healthcare capacities and infrastructural parameters. Furthermore, the Urban database is not populated for many of the seismic relevant cities in Europe (city level) and the database is still incomplete for many of the required variables shown in Table 7.4.

In order to operationalize the framework and be able to test the approach for the health impact model, data on national level was used instead. The indicators can be selected to represent the main criteria identified in the literature review and are shown in Table 7.5.

Table 7.5 Country-level indicators shown for different criteria influencing overall health impact

Social Vulnerability Factors		
Indicator based on literature research	**Available statistical Indicator**	**DATA Source, Level**
AGE / proportion of elderly and children	Elderly Coefficient Over 65 Under 9	EUROSTAT NUTS2
Gender: proportion of women in general and on elderly, proportion of pregnant women (would be good to have)	Female per 1000 Male	EUROSTAT
Income status / financial resources	Below National Poverty Line Unemployment Rate Long-time Unemployed	EUROSTAT
Social Status	?	?
Education and Iliteracy	Adult Illiteracy Rate	UNDP
Minorities / Migrants	Migrant rate per 1000 ppl	CIA
Environmental Health Factors		
Residential Crowding	Average number of persons per room Total Average number of persons per room Urban	UNDP
Population density	Population Density, total	World Bank EUROSTAT
Sanitation	Improved Sanitation Coverage (%) ISC Total	UNDP
Baseline Health Factors		

Health expenditures	Per capita total expenditure on health per capita	WHO
Health care access	Percent Health Access	EUROSTAT
Health Status	Malnutrition prevalence, weight for age (% of children under 5) Infant Mortality Rate Total	World Bank UNDP
Immunization	Percent children 12-23 months immunized	World Bank
Life Expectancy	Life Expectancy at Birth	UNDP
Health care Capacity Factors		
Hospital beds	Hospital Beds	WHO
Healthcare workers	Physicians per 1000 ppl Nurses and Midwives per 1000ppl Anasteologist Cardiolpgist Emergency Medicine General Surgeon Orthopedic Surgeon Rastdiolog Hospital Beds fo Thorax Surgery	World Bank World Bank EUROSTAT

7.3 MULTI-CRITERIA HEALTH IMPACT MODEL

The integrated health impacts model developed here is based on a multi-criteria decision theory (MCDA) framework which allows the bringing together of parameters influencing the direct social losses represented through estimates of casualties and injuries, with factors related to overall health impact of the population at risk in an earthquake. As shown in Fig. 7.9, the multi-criteria framework can be described schematically as composed of the two main criteria: overall population at risk of mortality in an earthquake (represented by Fatality) and an Impact Factor (IF). Subsequently, the overall health impact for a particular location (i.e., city district, county or country) can be described as the population at risk of mortality, amplified by the set of conditions that can aggravate the health impacts following a disaster which are derived as a weighted index of a set of indicators in four main categories of: social vulnerability, baseline health status, environmental parameters and healthcare capacity. This can be expressed by:

$$HII = F\ (1 + IF) \tag{7.4}$$

where:

HI = Health Impact Index

F = Indicator representing the mortality ratio from an event. When using a casualty estimation model this is taken as the ratio of the fatalities to occupants at a given location.

IF = Impact Factor represented as the weighted sum of indicators representing the categories social vulnerability, healthcare capacity, baseline health status and environmental parameters.

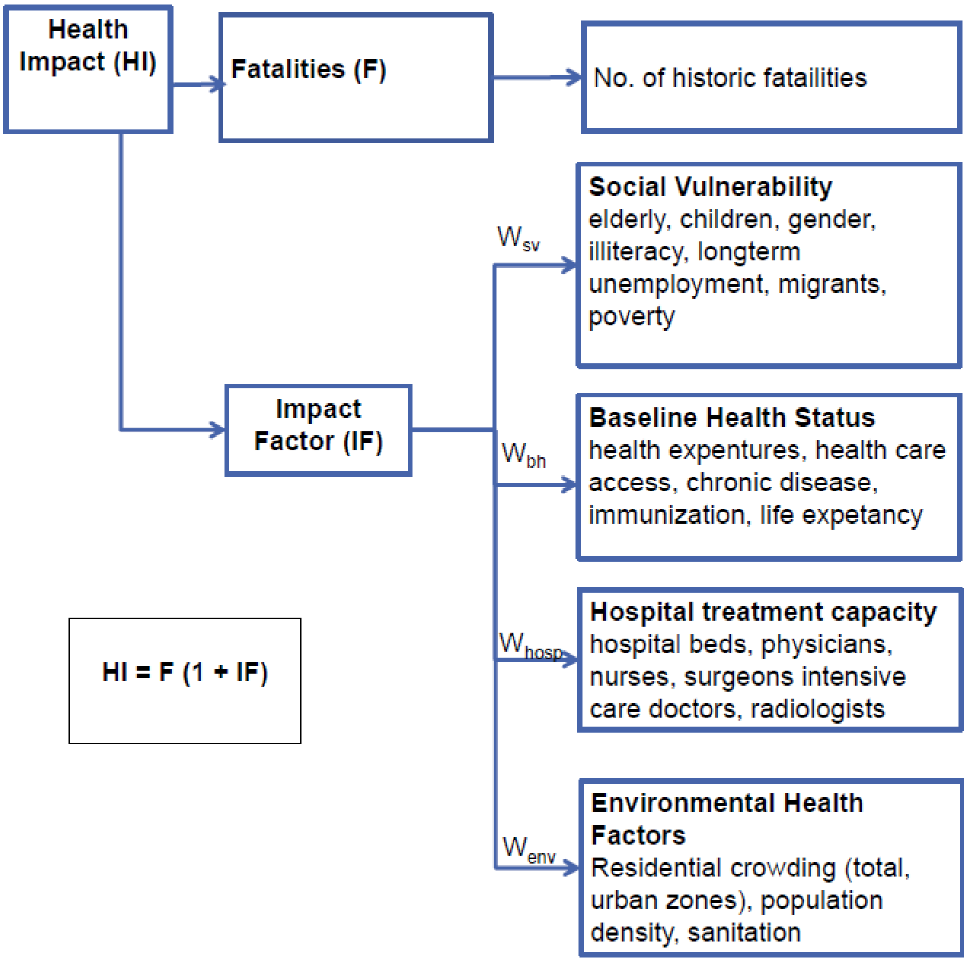


Fig. 7.9 Multi-criteria Framework for Health Impact Analysis

7.4 MODEL IMPLEMENTATION

To demonstrate the health impact methodology at the national level of analysis it has been applied to 12 European Countries representing the greatest seismic risk. The mortality ratio was obtained using detailed data on the number of dead persons from 244 events affecting 35 European countries from 1900 till 2012, which were reduced to the top 12 with the highest casualty estimates. Indicators representing the different categories of the impact factor were compiled from various sources including including EUROSTAT, UNDP, WHO, World Bank, and CIA. All indicators were derived for the year 2012. Multi-criteria decision analysis software was used to implement the methodology. The tool will allow stakeholders to display the Health Impact ranking of different countries using various output and visualization formats. The user can assign different importance (weights) to selected indicators and the tool can be used to discuss the weighting outcomes and interactively examine the variability of health impacts in different areas to different weighting schemes.

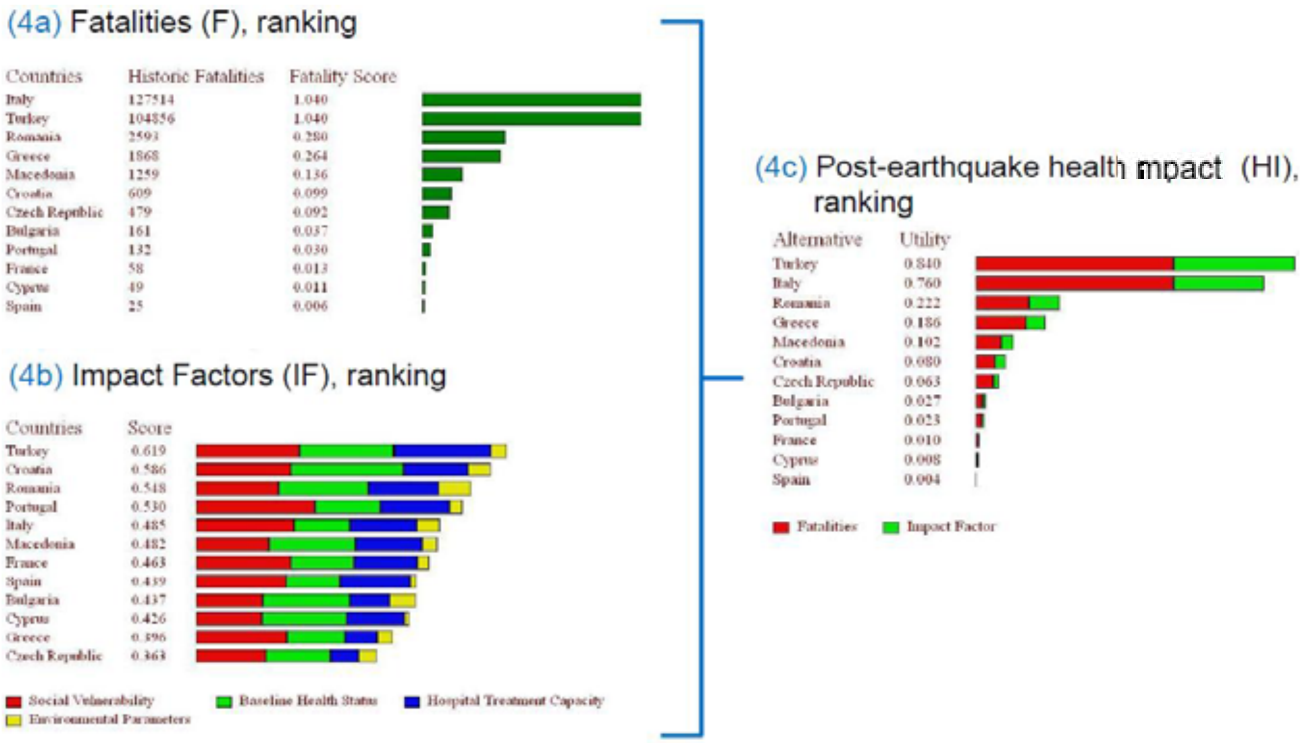


Fig. 7.10 Overall Health Impact (c) obtained as a product of Fatalities (a) and Impact Factors (b)

Fig. 7.10 shows the historic fatalities in each of the 12 European countries where it can be seen, for example, that Turkey and Italy are at a much greater risk for earthquake fatality than other countries. On the other hand, France, Cyprus and Spain show no to very few historic fatalities for the period captured in the analysis. It is recognized that the period for which historic data on fatality is available for each of these countries may underestimate the potential for earthquake mortality in some countries. In subsequent analysis the return period for earthquakes with potential to cause fatalities will also need to be accounted for in determining the mortality ratio. However, in using the methodology within the SYNER-G framework the mortality ratio is obtained simply as the ratio of the estimated casualty to the occupants of a given location. As mentioned already due to the lack of required indicators for a sub-city district level analysis the current implementation was done at a country level where historic fatality numbers are used to substitute the casualty estimation model. The ranking of the impact factor is also shown for each of the 12 countries. It can be observed that Turkey, for example, has the highest potential for overall health problems following an event due to lack of health care capacities, comparatively lower baseline health status and social vulnerabilities in addition to a very high historic earthquake fatality. Fig. 7.10 shows how social vulnerability is derived as weighted average of a number of indicators including elderly, children, gender, migrants, poverty, illiteracy and long-term unemployment. The assigning of weights to each of these indicators is a subjective process and their elicitation should be carried out in a participatory approach with a group of experts or other stakeholders using the model. Similarly the weight assigned to each category of the Impact Factor (IF) can be different and should also be determined in a participatory approach. In this analysis equal weights were given to social vulnerability, healthcare capacity and baseline health, whereas, the environmental parameters criteria were given a lower weight. A sensitivity analysis can be carried out to show how the ranking of the Impact Factor changes for the 12 countries as a function of the weight. Fig. 7.11 shows how some countries are very sensitive to the weight of the Social Vulnerability criteria. For example, Portugal and France are extremely sensitive and their low overall rank will increase significantly if the Impact Factor is determined only as a function of Social Vulnerability – in the case of Portugal it goes from having one of the lowest ranks to the highest rank. The MCDA software tool (see Technical Report D7.1 (Khazai et al., 2012b) for detailed description of software tool) can be used to change the weights of the indicators and interactively view the effect of this on the total output.

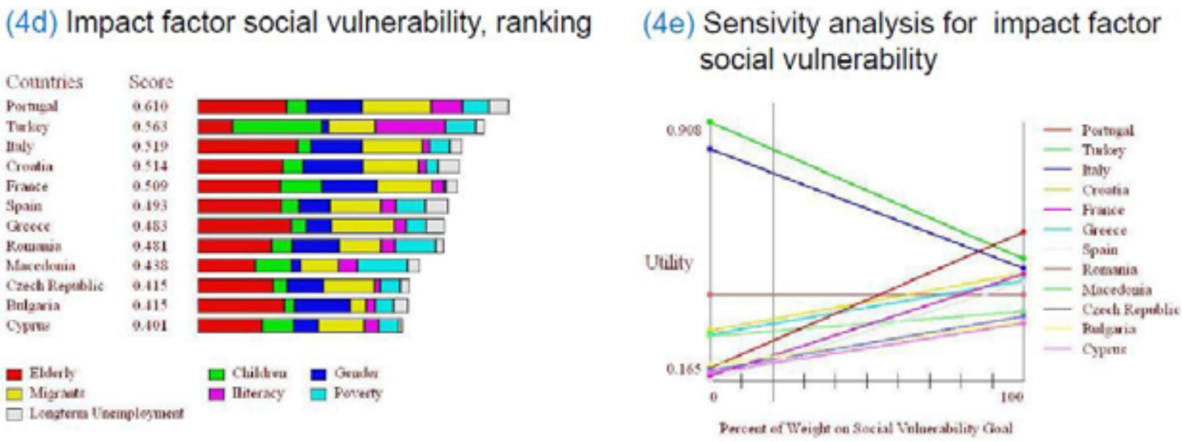


Fig. 7.11 Sensitivity of ranking outcome to weight of social vulnerability criteria

7.5 CONCLUSIONS AND SUMMARY

The implementation of the health impact model shows reasonable results for integrating social vulnerability and other factors affecting health impacts after disaster in a logical hierarchical model at a national level. The model is readily extendable to other scales (NUTS2, city, sub-city) where individual indicators are selected based on the specific context of the scale and availability of data. The preferred approach was to apply our framework to a sub-national, regional, city or sub-city level. However, based on the principle that only European-wide public available data should be used, this was not possible as the Urban Audit database does not contain enough relevant factors for criteria identified in this study.

A methodological problem and limitation in the implementation is that in the absence of using a casualty estimation model to compute the number of fatalities, empirical data on fatalities was used. It should be noted that the historic data used for the mortality ratio from earthquakes carry inherently within them the potentially aggravating effects of social vulnerability. In other words, the historic number of fatalities used in the implementation already account for the "impact factors" such as the baseline health of the occupant and the speed of post-earthquake care the occupant may or may not have received. Thus, these aggravating conditions may be double counted here. Furthermore, the fatality numbers represent only a limited historic window and can be overly biased by a large event which occurred in one of the countries but is still waiting to happen in another.

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Appendix A

A Existing socio-economic consequence functions

There have been many **existing global social consequence functions** which can be applied to Earthquake Loss Estimation tools. The following has been excerpted from Daniell (2009) and provides a list of several of the key consequence functions, where P denotes functions derived from damage alone, and SE denotes functions that include socio-economic effects.

- Coburn and Spence, 2002 – damage derived functions (P)
- Spence, 2007 – damage derived functions (P)
    - ATC-13 social functions – damage derived functions (injuries calculated from deaths) – occupancy based on floor area (P)
- Badal and Samardzhieva, 2003 – damage derived functions (P)
- KOERILoss functions – damage derived functions (P)
- Bal et al. (2008) – damage derived functions (P)
- MAEViz functions – mae.ce.uiuc.edu/software_and_tools/maeviz.html (P and SE)
    - Household and Population Dislocation
    - Business Content Loss, Interruption Loss, Inventory Loss
    - Shelter Needs & Supply Requirements
    - Social Vulnerability
    - Temporary Housing
- LOSS-PAGER functions – regionalization, relating intensity and social function to predict deaths – read Porter et al. (2008). PAGER-CAT database gives vulnerability codes and also allows for the MMI to be related to a fatality rate via probability curves due to variation from country to country using a predicted building stock. (L1, possibly L2 at a maximum). There are also semi-empirical and analytical methods, both of which use predicted damage data. (P and SE)

Similarly, existing economic consequence functions can also be applied for the SE section in some cases.

- Coburn and Spence, 2002 – damage derived functions (P)
- Spence, 2007 – damage derived functions (P).
- Complex functions are employed within MAEviz using Benefit-Cost functions based on Census tract data, fiscal impact etc. (all on a level 3 basis) (P and SE).

- OPENRISK is another such program which gives Loss Exceedance calculators which are all as a result of a given damage ratio (P and SE)
- Extensive modifications to functions within the other open source programs reviewed.

A.1 EXISTING SOFTWARE PROGRAMS WHICH CALCULATE SOCIO-ECONOMIC LOSSES (P AND SE)

For software packages, the socio-economic module has traditionally been the way that the damage data is converted to social and economic loss estimates as well as how these methods can be integrated in the majority of software cases i.e. the direct loss module section. For this case, the loss module can consist of any of the functions provided, written into the coding. The socio-economic indicator tool, will then correspond to the level of analysis applied in the physical loss section. i.e. the same exposure data and geographical area will be used.

A.1.1 Social Losses within chosen software packages

There is increasing social vulnerability and this can be correlated to development index, growth rate and other issues. Including social vulnerability, such as has been done in MAEviz, allows for a greater level of information to be obtained from the vulnerability modelling results for use in disaster response (homeless shelter needs etc. as detailed below in

. However, this also includes an increased amount of complexity.

Nevertheless, social losses are included to some degree in most of the ELE software packages reviewed. In some cases for the post-earthquake methods, disruption details are also included. DBELA has been updated to include social losses for Turkish systems. The occupancy criteria above affect the complexity of the calculations of social losses. For the injury data, the level indicates the severity of injuries (minor, moderate, major etc.). Many of the software packages calculate a level of displaced based on the top three levels of damage (Moderate, Severe and Collapsed) for HAZUS-based models, and similarly for other systems.

Table A.1 Social Losses for ELE Software Packages Reviewed (Daniell, 2008)

ELE Software	Deaths	Injured	Displaced	Other
CAPRA	YES	YES	YES	unconfirmed
CATS	YES	YES, Complex	YES, Complex	Detailed system & road disruptions
DBELA	YES	YES, 4 levels	YES	via Bal *et al.* (2008a)
ELER	YES	YES	YES	L0:Regionally adjusted fatality vs. EMS98 relationships AND L1, L2:damage-based, L0=Samardzhieva *et al.* (2002), L1=D4+D5 =deaths, 4xdeaths = injuries (ATC13)

ELE Software	Deaths	Injured	Displaced	Other
EmerGeo	YES	YES	YES	Privatised System
EPEDAT	YES	YES	YES	Day and night etc.
EQRM	YES	YES, 1 level	NO	
EQSIM	YES	YES, Hazus	YES	Advanced Recovery System
Extremum	YES	YES, 1 level	YES	
HAZ-Taiwan	YES	YES, 3 levels	YES & shelter needs, long-term housing	Night and Day, Indoor/Outdoor/Commuting, Disruptions
HAZUS-MH	YES	YES, 3 levels	YES & shelter needs, long-term housing	Night and Day, Indoor/Outdoor/Commuting, Disruptions
InLET	YES	YES, 3 levels	YES	
LNECLOSS	YES	YES	YES	
MAEViz	YES	YES, Comple x	YES, Complex	Social Vulnerability Analysis, Business Interruption Algorithms, Dislocation Analysis, Short Term Shelter Needs, Shelter Supply, Temporary Housing Data Analysis and Optimisation
OPENRISK	YES*	NO	NO	Damage-based
OSRE	NO	NO	NO	
PAGER	NO, P2:YE S	NO, P2:YES	NO, P2: YES	Population exposure, P2: integrates vulnerability and uses a 3 tier approach based on the PAGER-CAT. Prone areas = derive social loss from previous EQs, Developed = analytical models due to improved standards, Semi-empirical = function of collapse rates, occupancy and vulnerability for every country.
QLARM	YES	YES, 1 level	NO, not shown	Values are rapid estimations, QL2: improved estimates.
RADIUS	YES	YES	NO	
REDARS	NO	NO	NO	Travel time delays, Disruptions
RiskScape	YES	YES	YES (shelter needs)	Not set as yet – HAZUS based.
ROVER-SAT	NO	NO	NO	
SAFER	YES	YES	YES	

ELE Software	Deaths	Injured	Displaced	Other
SELENA	YES	YES, 3 levels	NO	Coburn and Spence adapted
SES2002 & ESCENARIS	YES	YES	YES	Coburn and Spence based
SIGE	YES	YES	YES	
SP-BELA	YES	YES, 4 levels	YES	via Bal *et al.* (2008b)
StrucLoss	YES	YES, 3 levels	NO	D4 and D5 combined = deaths

A.1.2 Economic Losses within chosen software packages

The economic losses can either be calculated as a result of direct or indirect loss (as explained previously). Most methods simply use the damage data and the MDR calculated from it, in order to derive an economic loss. No economic loss estimate will ever be exactly accurate; however MAEviz and HAZUS-MH should be identified due to the complexity of their calculations. OPENRISK investigates economic loss in depth using benefit-cost ratios, EAL and LE damage exceedance matrices. This is a proxy for the proprietary software packages. In addition, disaggregation is also possible within many economic loss softwares. This is where the economic information can be either defined for different ground motions or for particular magnitude-distance combinations, or as a full analysis (EQRM – Patchett *et al.*, 2005). As many of these ELE software packages have been produced for a certain test region, retrofitting studies have also been undertaken in order to compare whether it is better to retrofit before a disaster to reduce losses (but have the cost of retrofitting), or to not retrofit the building stock and simply have increased costs in the disaster. This is being currently taken into account for economics but could also include the social consequences (StrucLoss, LNECLOSS and OPENRISK).

Table A.2 Economic Losses for ELE Software Packages Reviewed (Daniell, 2008)

ELE Software	Direct	Indirect	Methods	Disaggregation
CAPRA	YES	Expect	Cost-benefit analysis, Damage-based, Indirect Module expected, HAZUS type etc.	YES
CATS	YES*	YES*	Now proprietary - Damage-based 10 yrs ago	YES*
DBELA	YES	YES	Damage-based user-defined methods	YES
ELER	NO*	NO*	Not seen in documentation but can be produced via damage calculations.	NO
EmerGeo	YES*	YES*	Proprietary	YES*
EPEDAT	YES	NO	Direct intensity based - insurance	NO
EQRM	YES	NO	Australian adapted, damage-based, 3 struc. Components, aggregated loss	YES
EQSIM	NO	NO	Future possible from Damage-based	NO

ELE Software	Direct	Indirect	Methods	Disaggregation
Extremum	YES	NO	Damage-based	NO
HAZ-Taiwan	YES	YES	HAZUS based	YES
HAZUS-MH	YES	YES	Direct: damage-based, structural, non-structural (Acc and Disp. Sensitive), contents, Indirect: Loss Module based on historic, time, disruption etc.	YES
InLET	Future	Future	Damage-based	unknown
LNECLOSS	YES	YES	Damage-based, Retrofitting	YES
MAEViz	YES	YES	Full Direct as HAZUS and Indirect including Fiscal impact, shelter, temp. housing, pop. Dislocation for buildings and utilities. Also utility functions.	YES
OPENRISK	YES	NO	Portfolio EAL, Single BCR, LE, EAL via Damage Exceedance Matrices	Possible
OSRE	YES	NO	Loss curve	NO
PAGER	NO	NO		NO
QLARM	YES, QL2: YES	QL2:YES	Direct damage cost, disaster management	QL2:Possible
RADIUS	NO	NO		NO
REDARS	YES	YES	Network Analysis, component performance,	YES
RiskScape	YES	YES	Unknown methods as yet. Community disruption, downtime for indirect costs etc.	unknown
ROVER-SAT	NO	NO		NO
SAFER	YES	unknown	u/c	unknown
SELENA	YES	NO	Structural damage - direct	NO
SES2002 & ESCENARIS	YES	NO	%GNP and value, damage-based	NO
SIGE	YES	NO	Loss curve - direct	NO
SP-BELA	YES	YES	Damage-based User-defined methods	YES
StrucLoss	YES	NO	Geocell Damage-based, Retrofitting also	YES

Appendix B

B Available socio-economic data for L'Aquila

The source is the Istituto Nazionale di Statistica (ISTAT) which deals with the Italian statistical system. In particular the data refer to the 14th General Census of Population and Housing (2001), and are related to socio-demographic characteristics of the resident population and the structural characteristics of housing and buildings.

The territorial scale of the statistics available can be summarized as follows:

- Regional data (NUTS 2: population of the Abruzzo region = 1.262.392)
- Provincial data (NUTS 3: population of the L'Aquila province = 297.424).
- Municipality data (NUTS 4 and 5: population between 500 and 80.000).

In particular in the following table, available data from the14th General Census of Population and Housing (2001), refer to the Abruzzo (NUTS 2) and L'Aquila city (NUTS 3) (October 21, 2001) are shown:

Table B.1 14th General Census of Population and Housing, in Abruzzo and L'Aquila (October 21, 2001). ISTAT.

Indicators Spatial Unit	
Resident population, foreign residents, family and cohabitation, number of municipalities, households and cohabitation size class population of municipalities.	R,P
Resident population by marital status, sex and single year of age.	R,P
Resident population by marital status, sex, date of birth and age.	R,P
Resident population in the age of 6 years and over by educational attainment, sex and age group.	R,P
Resident population in the age of 6 years and over by age, sex and educational qualification.	R
Resident population belonging to the labor force status, sex and age group.	R,P
Resident population belonging to the labor force status, sex and educational level.	R,P
Resident population belonging to the labor force status, sex and marital status.	R,P
Resident population aged 15 and over by employment or non-professional status, sex and single year of age.	R
Resident population aged 15 and over to attend courses of training, gender and employment status or unprofessional.	R

Employment by employment status, sex and age group.	R,P
Employment by employment status, sex and sector of economic activity.	R,P
Employment by age, sex and work placements.	R,P
Employment by age, sex, section of economic activity and professional status.	R,P
Employed persons by educational attainment, sex, economic activity and professional status.	R,P
Employment by professional status, sex and number of hours worked.	R,P
Employment by type of work, sex and age group.	R
Employment by marital status, sex and work placements.	R
Employment by marital status, sex, section of economic activity and professional status.	R
Employment by section of economic activity, sex and single year of age.	R
Employment by economic activity, sex, professional status and single year of age.	R
Employed persons by educational attainment, gender and work placements.	R
Employment by type of work, sex and educational level.	R
Employment by type of work, sex and work placements.	R
Employment by hours worked, sex and work placements.	R
Employment by hours worked, sex and age group.	R
Busy employees for employment, gender and educational level.	R
Busy employees for employment, gender and age group.	R
Resident population not in the labor force by non-professional status, gender and age group.	R,P
Resident population not in the labor force by non-professional status, gender and marital status.	R,P
Resident population not in the labor force by non-professional status, gender and educational level.	R,P
Resident population in search of first employment by age, sex and educational qualification.	R
Resident population by using one or more housing or cohabitation other than their usual residence, duration of use, sex and age group.	R,P
Local residents who have lived for more than 90 days in one or more housing or cohabitation other than their usual residence by main reason for use, sex, duration of use and age.	R,P
Residents who lived in accommodation / living together different from that of usual residence for more than 90 days for marital status, sex and age group..	R
Households by type and number of components of the family.	R,P
Households by number of members of the family and living situation.	R,P
Families by number of components, sex, marital status and age of reference person of the family.	R

Person households not living together in housing by number of rooms and age.	R
Person households not living together by type of housing, tenure and age.	R
Households by number of children, type of nucleus and age of children	R,P
Households consisting of a single parent of 15 years and over by age, gender and professional status or professional parent.	R
Households consisting of a single parent and children to the number of children, presence of minor children and other residents, by sex and age of the parent.	R
Couples by age of partner, presence and number of children.	R,P
Condition Torques for him, her condition, number of children and marital status of the couple.	R
Couples for marital status, presence and number of children.	R
Couples for marital status of partners and the presence of children.	R
Resident population by type of living in cohabitation, sex and age group.	R,P
Resident population by type of living in cohabitation, sex and main reason to stay in coexistence.	R,P
Population living in cohabitation for marital status, sex and type of cohabitation.	R
Components present in cohabitation by type of cohabitation, sex and main reason for staying / living presence.	R,P
Components present in cohabitation by age, sex and type of cohabitation.	R
Components include a live-in number of components in living together, sex and type of cohabitation.	R
Components present in cohabitation for marital status, sex and type of cohabitation.	R
Partnerships for the number of components present in cohabitation, sex and type of cohabitation.	R,P
Foreign resident population by age, gender and region of citizenship.	R,P
Foreign resident population by marital status, gender and region of citizenship.	R,P
Foreign resident population in the age of 6 years and over by educational attainment, sex and age group.	R,P
Foreign resident population in the age of 6 years and over by educational attainment, gender and region of citizenship.	R,P
Foreign resident population by age workers, gender and region of citizenship.	R,P
Foreign population resident abroad for main reason for the presence in Italy, gender and region of citizenship.	R
Foreign population resident abroad for marital status, gender and region of citizenship.	R
Foreign resident population employed abroad by geographical area of citizenship and economic activity.	R
Foreign resident population by geographical area occupied foreign	R

citizenship and age.	
Foreign population resident abroad occupied by age, sex and economic activity.	R
Foreign population living abroad for 15 years and most non-professional or professional status, gender and region of citizenship.	R
Foreign population living abroad for 15 years and most non-professional or professional status, gender and age group.	R
Foreign resident population was born abroad main reason for the transfer to Italy, gender and region of citizenship.	R
Foreign resident population was born abroad for years to transfer to Italy, gender and region of citizenship.	R
Families with at least one foreign resident of number of family members and the number of foreigners.	R,P
Households with at least one geographic area of foreign nationality of the components.	R,P
Buildings and complexes of buildings used and not used for type.	R,P
Residential buildings for conservation status, type of material used for the structure and age of construction.	R,P
Residential buildings for the number of steps and number of extensions.	R
Dwellings by building type and occupancy status, other types of housing, households and population by type of building.	R,P
Dwellings in total and occupied by persons living in residential buildings for construction time and number of housing building.	R,P
Dwellings occupied by residents for the number of occupants, bedrooms, and family members for tenure and number of rooms.	R ,P
Dwellings occupied by residents by period of construction of the building, tenure and the legal form of the owner.	R,P
Dwellings occupied by residents for the number of rooms, class size and age of construction of the building.	R,P
Dwellings occupied by residents for class size, availability and number of kitchens, number of bathtubs and shower facilities, number of toilets and number of levels.	R,P
Dwellings occupied by residents for tenure, type of services in the home and car.	R,P
Dwellings occupied by residents with heating fuel type or energy that powers the heating and hot water availability.	R
Dwellings occupied by residents with heating type of heating and type of fuel or energy that feeds the heating system.	R
Dwellings occupied by residents by number of rooms and shape of the legal owner.	R
Rooms in dwellings occupied by residents by number of rooms and type of housing services.	R
Population living in the family home in the number of family members and type of housing services.	R

Moreover, a subset is available for the lower spatial unit (Municipal) and it summarized in the following table:

Table B.2 14th General Census of Population and Housing, in L'Aquila Municipality (October 21, 2001). ISTAT.

Indicators Spatial Unit	
Land area, population density, population, households, buildings and houses by town.	M
Resident population by age and municipality.	M
Resident population by marital status and municipality.	M
Resident population in the age of 6 years and over by level of education and policy.	M
Resident population aged 15 and over by professional and non-professional status and municipality.	M
Employment by professional status and municipality.	M
Employment by economic activity and section of town.	M
Families by number of household members, and the municipality.	M
Households by type of unit and municipality.	M
Foreign resident population by geographical area of citizenship and municipality.	M
Residential buildings by period of construction and the municipality.	M
Dwellings occupied by residents, occupants and rooms for Tenure and municipality.	M
Dwellings occupied by residents, families and components for number of rooms and municipality.	M
Dwellings occupied by residents for these types of services, and municipality area.	M
Resident population and households by type of inhabited places, sex and municipality.	M
Buildings and houses inhabited by type of location and municipality.	M
Altitude, resident population by sex, number of households, buildings and dwellings, inhabited by town and village.	M

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Title: **Guidelines for the consideration of socio-economic impacts in seismic risk analysis**

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Abstract
A unified approach for modelling shelter needs and health impacts caused by earthquake damage which integrates social vulnerability into the physical systems modelling approaches has been developed. The shelter needs and health impact models discussed here brings together the state-of-the-art social loss estimation models into a comprehensive modelling approach based on multi-criteria decision support, which provides decision makers with a dynamic platform to capture post-disaster emergency shelter demand and health impact decisions. The focus in the shelter needs model is to obtain shelter demand as a consequence of building usability, building habitability and social vulnerability of the affected population rather than building damage alone. The shelter model simulates households' decision-making and considers physical, socio-economic, climatic, spatial and temporal factors in addition to modelled building damage states (input from WP3 and WP5). The health impact model combines a new semi-empirical methodology for casualty estimation with models of health impact vulnerability, transportation accessibility and healthcare capacity to obtain a holistic assessment of health impacts in the emergency period after earthquakes. A group of proposed socio-economic indicators were derived based on an in-depth study of disaster literature for each of the shelter, health and transport accessibility models, and harmonized based on data available for Europe from the EUROSTAT Urban Audit Database.

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